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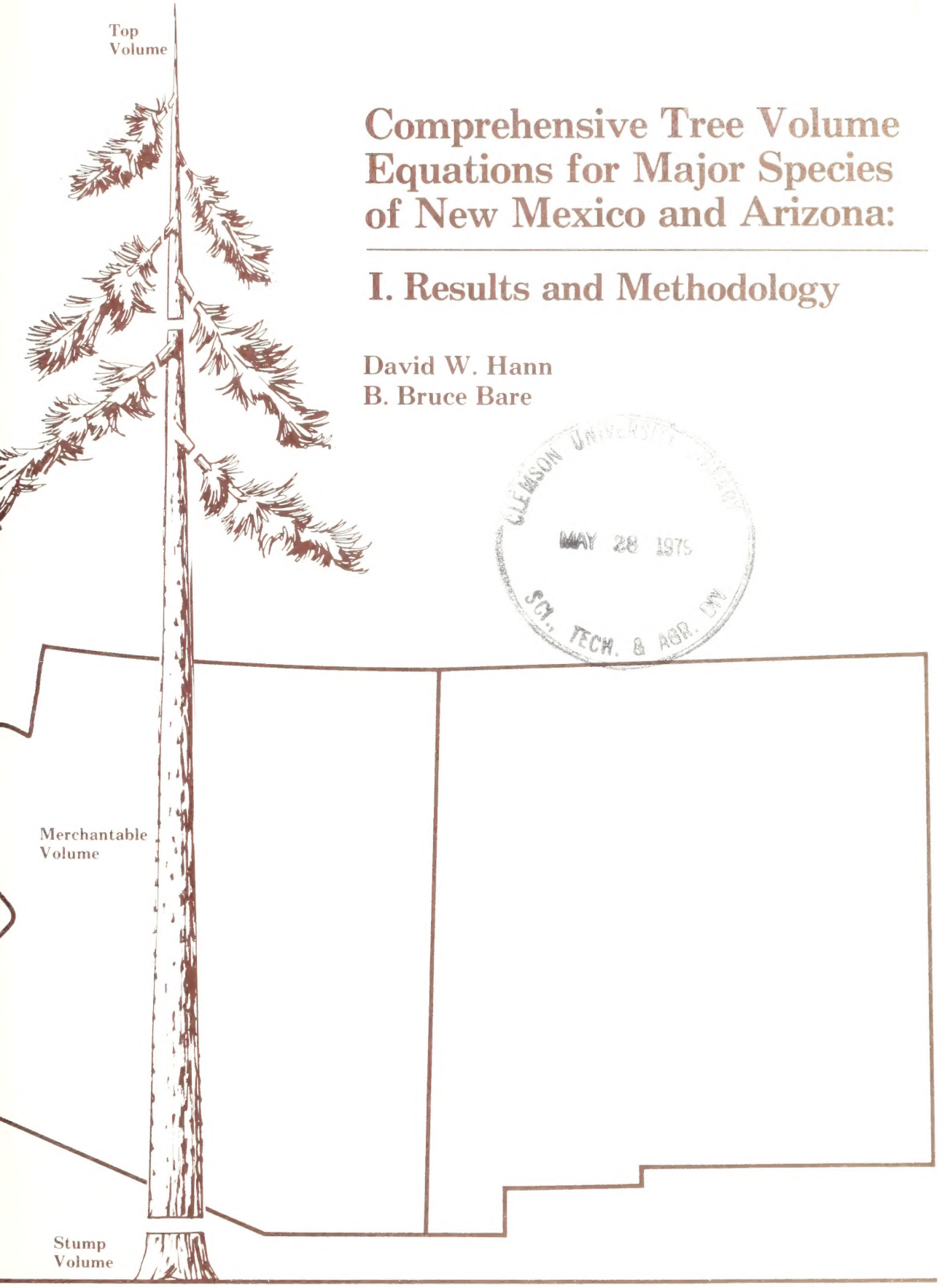

Comprehensive Tree Volume Equations for Major Species of New Mexico and Arizona:

I. Results and Methodology

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COMPREHENSIVE TREE VOLUME EQUATIONS FOR MAJOR SPECIES OF NEW MEXICO AND ARIZONA:

I. RESULTS AND METHODOLOGY

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RESEARCH SUMMARY

Comprehensive tree volume equations and the methodology used to derive them are presented for the major tree species of New Mexico and Arizona. With these equations, the following gross and net volume types can be computed for both unforked and forked trees: total stem cubic foot volume; merchantable cubic foot volume to any top diameter between 3 and 8 inches, inside bark; International 1/4-inch board foot volume to a 6-inch top, inside bark; and Scribner board foot volume to a 6-inch top, inside bark. These equations were developed in such a manner as to eliminate many of the problems of consistency, compatibility, reliability, and flexibility associated with previous sets of volume equations. This approach also allows the user to divide total stem cubic foot volume into top volume, merchantable volume, and stump volume. This last feature is useful for predicting the level of residues after harvesting to various top diameters.

INTRODUCTION

Today, as in the past, the accurate estimation of tree volume is an essential pre-
uisite for foresters involved with timber management planning, forest surveys, damage
raisal, timber sale preparation, trespass, and condemnation proceedings as well as
wth and yield studies. To be of immediate value, volume estimates must be expressed
units of measure related directly to the products derived from the tree. The board
t and the cubic foot are traditional units of measure, although the latter is
reasing in importance as utilization of the total tree becomes more common. However,
is also recognized that cubic foot volume, when combined with square feet of circum-
ential surface and linear feet, provides for more consistent and accurate estimates
a tree's product potential (Grosenbaugh 1954; Davis and others 1962; Bruce 1970).
s, future needs of foresters may well require estimates in these units of measure as
l as the traditional board foot. This paper is concerned solely with tree volume
imation in the Southwest. Surface area equations for selected species in the same
a were provided by Hann and McKinney (1975).

All of the early volume tables and equations published for exclusive use in
zona, New Mexico, or both were for the prediction of unforked, gross Scribner board
t volume to an 8-inch top. When volume equations were developed, the logarithmic
hod described by Schumacher and Hall (1933) was followed (Hornibrook 1936; Lexen and
mson 1938a, 1938b; Peterson 1939b, 1939c, 1939d; Lexen and Peterson 1939b, 1939c,
9d; and Krauch and Peterson 1943). When this method did not work, the alinement chart
hod was used (Peterson 1939a; Lexen and Peterson 1939a; and Krauch and Peterson
3). These early equations and tables were for "blackjack" or immature ponderosa pine
rnibrook 1936; Peterson 1939b), "yellow" or mature ponderosa pine (Hornibrook 1936;
erson 1939c), combined ponderosa pine (Peterson 1939d), white fir (Lexen and Thomson
8a; Lexen and Peterson 1939a), southwestern white pines (Lexen and Thomson 1938b;
erson 1939a), Apache pine (Lexen and Peterson 1939b), Arizona pine (Lexen and Peter-
1939c), Chihuahua pine (Lexen and Peterson 1939d), and Douglas-fir (Krauch and
erson 1934).

In addition to these, Meyer (1938) published gross volume tables for unforked
derosa pine derived from data collected in several western States, including the
thwest. Volumes were given in three units of measure--total stem cubic foot, Inter-
ional 1/8-inch, and Scribner board foot.

More recently, the logarithmic method has been used to develop equations for
orked, gross Scribner board foot volume to an 8-inch top in white fir (Peterson 1958)
in Englemann spruce (Peterson 1961), and for unforked, gross cubic foot volume to
h a 4- and an 8-inch top in immature and mature ponderosa pine (Gaines and Peterson
0). Minor (1961) used weighted, least squares regression to develop an equation for
orked, gross cubic foot volume to a 4-inch top in ponderosa pine, whereas Myers
63) used ordinary, least squares regression with segmented data to develop unforked,
ss volume equations for (a) total stem cubic foot volume, (b) merchantable cubic foot
ume to a 4-inch and variable top limit, and (c) International 1/4-inch and Scribner
rd foot volumes to a variable top limit. (Myers used the term "variable top limit"

to indicate that the merchantable top diameter was a fixed function of a tree's diameter breast height and not to indicate that the top diameter was an independent variable in the volume equation. The latter type of equation can be converted to the former by defining the functional relationship between d.b.h. and top diameter.)

The purpose of this study was to develop gross and net tree volume equations for forked and unforked trees of the major tree species found in Arizona and New Mexico. Species-National Forest (sp-NF) specific equations were developed for the following units of measure--total stem cubic foot volume, merchantable cubic foot volume for any top diameter between 3 and 8 inches, and International 1/4-inch and Scribner board foot volumes to a 6.0-inch top. The resulting equations and methodology used to derive these equations are described in this paper. Volume tables for use in the field appear in a companion piece, "Comprehensive tree volume equations for major species of New Mexico and Arizona: II. Tables for unforked trees."

The present study provides a complete set of standardized gross and net volume equations for the major species, forked or unforked, in Arizona and New Mexico. In addition, all equations are derived from a common data base. Further, modeling procedures were adopted to ensure that (a) net volumes do not exceed gross volumes, (b) reasonable board foot-cubic foot ratios prevail, and (c) Scribner board foot volumes do not exceed International 1/4-inch board foot volumes. Merchantable cubic foot volume equations for any top diameter between 3 and 8 inches also are provided, thus permitting users of the equations to adapt to changing merchantability standards.

SOURCE AND NATURE OF DATA

The data were collected from five National Forests of Arizona and New Mexico by field crews of the Division of Timber Management, Southwestern Region, Forest Service, Albuquerque, New Mexico (table 1).

The data for the Coconino, Tonto, and Lincoln National Forests are the same as used by Hann and McKinney (1975) in the development of surface area equations. On the Santa Fe and Carson National Forests, the measurement trees were selected by line sampling with a 40 basal area factor angle. The lines were located and trees designated by inventory field crews traveling to randomly selected continuous forest inventory plots. Later, a second crew felled and measured as many of the designated trees as could be finished in one working day, using procedures similar to those described by Stage and others (1968).

Tree volumes were computed using a modified version of the NETVSL computer program (Stage and others 1968). Merchantable volumes were determined to various top diameters and to a 1-foot stump on all National Forests except the Lincoln, where stump height was 1.2 feet.

Table 1.--*Data sources*

Species	National Forest				
	Coconino	Tonto	Lincoln	Santa Fe	Carson
Blackjack pine[1] (*Pinus ponderosa* Laws.)	X	X	X	X	X
Yellow pine[1] (*Pinus ponderosa* Laws.)	X	X	X	X	X
Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Mirb.] Franco)		X	X	X	X
White fir (*Abies concolor* [Gord. and Glend.])			X	X	X
Southwestern white pine (*Pinus flexilis* var. *reflexa* Engelm.)			X	X	X
Engelmann spruce (*Picea engelmannii* Parry)			X	X	X
Aspen (*Populus tremuloides* Michx.)				X	X
Corkbark fir (*Abies lasiocarpa* var. *arizonica* [Merriam] Lemm.)				X	X

[1]In the Southwest, blackjack and yellow pines are distinguished by their bark colors; blackjack pines have very dark bark and yellow pines heavily plated, orange bark. This distinction is based on age, growth, and vigor differences rather than botanical differences, but foresters have found it useful in forest management planning.

RESULTS

Final equations for predicting the various types of tree volume follow, along with an explanation of how to apply them. Details concerning the methodology can be found in the appendixes.

A statistic that will be presented whenever possible is the relative mean-squared residuals (RMSQR) of the final equation. RMSQR is the quotient of mean-squared residuals divided by the variance of the dependent variable and, as such, is an index of fit similar to the coefficient of determination (R^2). In the case of RMSQR, however, perfect fit would result in a value of 0. A fit that would not reduce the squared residuals below the value around the mean would result in a value of 1, and a value greater than 1 would indicate that the model has increased variability. The advantage of RMSQR over R^2 is that only the former will reflect the loss in degrees of freedom that results from adding another independent variable; therefore, it serves as a better measure for comparing equations of different numbers of independent variables to see if the added variable(s) reduced variance about the regression model.

The standard error of the estimate is not reported here because the methodology used precluded the calculation of a meaningful statistic.

Gross volumes.--The appropriate equations for computing gross volume are chosen by the user on a tree-by-tree basis. If the tree is unforked, then the unforked tree volume equation is chosen based on the sp-NF combination of the tree. If the tree is forked, the unforked tree volume is first computed for the tree and then corrected for forking by the appropriate forked tree equation for the sp-NF combination of the tree. These seemingly trivial facts are brought out because the choice of which net volume equation to use is not on a tree-by-tree basis, but instead is determined for an entire data set.

A tree is considered forked if a fork of any severity occurs between breast height and the tip of the tree. For most of the species, two equations are given. The first equation utilizes tree size information only, while the second equation incorporates two independent variables that relate to the severity of forking. In all cases, the second equation has a lower RMSQR value. The position of the first fork variable, P, is defined as the height to the first fork divided by total tree height. The number of tips variable, T, can be counted directly or computed by adding 1 to the number of forks. All forks between breast height and the tip of the tree should be counted regardless of their severity.

Total Stem Gross Cubic Foot Volume--Unforked Trees

The total stem gross cubic foot volume of unforked trees is predicted from the odel:

$$V_t = a_0 + a_1 D^2 H$$

here

V_t = Predicted total stem gross cubic foot volume of an unforked tree

D = Diameter at breast height (d.b.h.) in inches

H = Total tree height in feet.

he sp-NF specific, weighted least squares regression coefficients, a_0 and a_1, are found table 2, along with the number of trees used in their development and the resulting MSQR. Methodological details can be found in appendix I.

Table 2.--*Unforked tree total stem gross cubic foot volume data base and regression results*

Species	National Forest	Number of trees	Regression coefficients		Relative mean squared residual
			a_0	a_1	
ite pine	Lincoln, Santa Fe, Carson	43	0.160888987	0.00203250045	0.0177
gelmann spruce-corkbark fir	Lincoln, Santa Fe, Carson	155	.225466084	.00216969983	.0329
llow pine	Coconino, Tonto, Lincoln, Santa Fe, Carson	201	.237204154	.00221122919	.0292
ackjack pine	Coconino, Tonto, Lincoln	[illegible]	.0810724804	.00198351037	.0266
ackjack pine	Santa Fe, Carson	220	.0483082948	.00204968419	.0435
uglas-fir	Lincoln, Tonto	108	.438373815	.00175642739	.0162
uglas-fir	Santa Fe, Carson	81	.341133398	.00191796994	[illegible]
pen	Santa Fe, Carson	109	.0327	.00231123522	.0199
ite fir	Lincoln	[illegible]	.210903832	.00183995833	.0213
ite fir	Santa Fe, Carson	[illegible]	.157776859	.00200912252	.0277

Total Stem Gross Cubic Foot Volume--Forked Trees

The model for total stem gross cubic foot volume of forked trees is

$$V_{t,f} = V_t \times R_{t,f}$$

where

$V_{t,f}$ = Predicted total stem gross cubic foot volume of a forked tree

V_t = Predicted total stem gross cubic foot volume of an unforked tree

$R_{t,f}$ = Predicted ratio of actual total stem gross cubic foot volume in a forked tree divided by predicted total stem gross cubic foot volume in an unforked tree of same dimensions.

The sp-NF specific equations for $R_{t,f}$, their RMSQR, and the number of trees used are found in table 3. An examination of RMSQR values indicates that, in some cases, models are only slightly better than the mean of ratios. Therefore, the mean values for $R_{t,f}$ are also included in table 3 for those who do not feel comfortable using the equations. Methodological details can be found in appendix II.

Table 3.--*Forked tree total stem cubic foot volume data base and regression results*

Independent variables

D = D.b.h. in inches
H = Total tree height in feet
P = Height to first fork divided by H
T = 1 + (number of forks)

Species, National Forest, and regression equations	Mean $R_{t,f}$	Number of trees	Relative mean squared residual (RMSQR)
White pine on Santa Fe, Carson, and Lincoln			
$R_{t,f}$ = 8.72597123E-01 + 2.96964121E-03(H)	1.03680	17	0.8803
or $R_{t,f}$ = 0.83242764 + 2.81237312E-05(H^2) + 1.67572359E-01(P)	1.03680	17	.8137
Engelmann spruce-corkbark fir on Santa Fe, Carson, and Lincoln			
$R_{t,f}$ = 9.92085233E-01 + 1.87806305$(D/H)^2$	1.12229	16	.7702
or $R_{t,f}$ = 0.49137954 + 3.73898958E-02(D) - 5.87687943E-05(H^2) + 5.08620456E-01(P)	1.12229	16	.5139
Ponderosa pine on Lincoln, Coconino, Tonto, Santa Fe, and Carson			
$R_{t,f}$ = 9.86799996E-01 + 4.82642048E-01$(D/H)^2$	1.02667	158	.9889
or $R_{t,f}$ = 0.90259661 + 1.24540324E-02(T^2) + 9.74033859E-02(P)	1.02667	158	.9374
Douglas-fir on Santa Fe, Carson, Lincoln, and Tonto			
$R_{t,f}$ = 9.40292266E-01 + 3.38586950(1/H)	1.00723	21	.9790
Aspen on Santa Fe and Carson			
$R_{t,f}$ = 9.49182022E-01 + 2.82537481E-05(H^2)	1.02097	37	.9559
or $R_{t,f}$ = 1.36944003 + 3.87833769E-05(H^2) - 5.61174592E-02(T) +3.69440030E-01(P^2) - 7.38880060E-01(P)	1.02097	37	.8975
White fir on Santa Fe, Carson, and Lincoln			
$R_{t,f}$ = 9.10060854E-01 + 2.67134214E-01(H/D^2)	.97591	13	.8752

Merchantable Gross Cubic Foot Volume

By definition, merchantable gross cubic foot volume in an unforked tree is equal total stem gross cubic foot volume minus the cubic foot volume in both the top and e stump (Husch 1963). This relationship can be written as

$$V_m = V_t - V_u$$

ere

V_m = Predicted merchantable gross cubic foot volume to a specified top in an unforked tree

V_t = Predicted total stem gross cubic foot volume in an unforked tree

V_u = Predicted unmerchantable gross cubic foot volume in an unforked tree (that is, the gross cubic foot volume in the top and stump of an unforked tree).

ighted least squares regression was used to develop the following model for unmer-antable gross cubic foot volume in an unforked tree:

$$V_u = b_0 + b_1 \frac{D^2H}{D_m^n} + b_2 D^2$$

ere

V_u = Predicted unmerchantable gross cubic foot volume in an unforked tree

D = D.b.h. in inches

H = Total tree height in feet

D_m = Any specified top diameter between 3 and 8 inches inside bark

n = An sp-NF specific power on d.b.h.

The appropriate regression coefficients, their RMSQR, and the number of observa-ons used can be found in table 4. The number of observations differs from the number trees used because each tree has an unmerchantable volume for each of the several top ameters computed for the tree. Methodological details can be found in appendix III.

Table [illegible]

Species	National Forest	Number of observations					
White pine	Santa Fe, Carson, Lincoln	250	1.5	-0.213005397	0.00491211378	0.006060061971	0.0229
Engelmann spruce-corkbark fir	Santa Fe, Carson, Lincoln	810	1.5	-.266475206	.00612895037	.007431115[illegible]	.0503
Yellow pine	All	1,206	1.0	.0185465259	.000788175798	.00505513624	.1004
Blackjack pine	Lincoln, Coconino Tonto	1,086	1.5	-.125349396	.00360421889	.005406 34204	.0591
Blackjack pine	Santa Fe, Carson	1,231	1.5	-.133967845	.00650174839	.00490223789	.0657
Douglas-fir	Lincoln, Tonto	[illegible]	1.0	-.083148657	.00121904459	.00541744598	.0547
Douglas-fir	Santa Fe, Carson	424	1.5	-.187630869	.00671872085	.00536451038	.0580
Aspen	Santa Fe, Carson	528	1.5	-.236432433	.00580208490	.00608042504	.0435
White fir	Lincoln	244	1.0	-.182699690	.00124824607	.00624477874	.3681
White fir	Santa Fe, Carson	298	1.5	-.187563245	.00632648558	.00604132385	.0293

Merchantable Gross Cubic Foot Volume--Forked Trees

The equation form for forked tree merchantable gross cubic foot volume is

$$V_{m,f} = V_m \times R_{m,f}$$

where

$V_{m,f}$ = Predicted merchantable gross cubic foot volume of a forked tree

V_m = Predicted merchantable gross cubic foot volume of an unforked tree

$R_{m,f}$ = Predicted ratio of actual merchantable gross cubic foot volume in a forked tree divided by predicted merchantable cubic foot volume in an unforked tree of same dimensions.

The sp-NF specific equations for $R_{m,f}$, their RMSQR, and the number of observations used can be found in table 5. For those who do not feel comfortable using these equations, equations that predict $R_{m,f}$ as a function of top diameter alone can also be found in table 5. Methodological details can be found in appendix IV.

Table . - [illegible] and regression results

Independent variables

D = D.b.h. in inches — D_{ob} = Top diameter, inside bark, in inches

H = Total tree height in feet — P = Height to first fork divided by H

T = 1 + (number of forks)

Species, National Forest, and regression equations	Number of observations	Relative mean squared residual
White pine on Lincoln, Santa Fe, and Carson		
$R_{ob,s} = C_0 + C_1 H$	101	0.9581
$C_0 = 0.61725167 + 0.042365845 D_{ob}$		
$C_1 = 0.00598501 - 0.00073445 D_{ob}$		
or $R_{ob,s} = 1.04518089 - 7.88395198E\text{-}07 D_{ob}^7 + 8.39079873E\text{-}08 D^8$		
Engelmann spruce-corkbark fir on Lincoln, Santa Fe, and Carson		
$R_{ob,s} = C_0 + C_1 (D/H)^2$	91	.9719
$C_0 = 0.88977465 + 0.01260886 D_{ob}$		
$C_1 = 2.02369991 + 0.00029092 D_{ob}$		
or $R_{ob,s} = 1.09275293 + 1.66824359E\text{-}06 D_{ob}^7 - 2.22920473E\text{-}07 D^8$		
Ponderosa pine on Coconino, Tonto, Lincoln, Santa Fe, and Carson		
$R_{ob,s} = C_0 + C_1 (D/H)$	937	.9968
$C_0 = 1.025717571 - 0.01509060 D_{ob}$		
$C_1 = 0.13600973 + 0.09709709 D_{ob}$		
or $R_{ob,s} = 0.997113216 - 0.023300125 D_{ob} + C_0 T^{-1} + C_1 P$	937	.9761
$C_0 = 0.00564984 + 0.00079885 D_{ob}$		
$C_1 = 0.002886816 + 0.02330013 D_{ob}$		
or $R_{ob,s} = 1.01577735 - 1.68401836E\text{-}06 D_{ob}^5$		
Douglas-fir on Lincoln, Santa Fe, and Carson		
$R_{ob,s} = C_0 + C_1 H^{-1} + C_2 H^{-1} D_{ob}$	118	.9064
$C_0 = 0.552116849$		
$C_1 = 22.5535301$		
$C_2 = 0.284962111$		
or $R_{ob,s} = 0.951125601 - 7.62321367E\text{-}04 D_{ob}^4 + 2.09712628E\text{-}03 D_{ob}^{3.5}$		
Aspen on Santa Fe and Carson		
$R_{ob,s} = C_0 + C_1 H$	184	.9165
$C_0 = 1.143728271 - 0.08851433 D_{ob}$		
or $C_1 = -0.000006413 + 0.000018827 D_{ob}$		
$R_{ob,s} = 1.07666448 - 1.18133616E\text{-}03 D^2$		
White fir on Santa Fe, Carson, and Lincoln		
$R_{ob,s} = C_0 + C_1 (H/D)$	74	.7286
$C_0 = 0.673711298 + 0.055948391 D_{ob}$		
or $C_1 = 1.709640750 - 0.348134538 D_{ob}$		
$R_{ob,s} = 0.983293776 - 2.40166266E\text{-}05 D_{ob}^4$		

Gross Cubic Foot Stump Volume--Unforked and Forked Trees

Unmerchantable gross cubic foot volume is composed of both stump volume and top volume. Information concerning the amount of top wood left after logging can be very useful for residue and fire assessments. Weighted least squares regression was used to fit the following gross cubic foot stump volume equation:

$$V_{gt} = g_0 + g_1 D^2$$

where

V_{gt} = Predicted gross cubic foot stump volume in an unforked or forked tree

D = D.b.h. in inches.

The appropriate regression coefficients, their RMSQR, and the number of trees used can be found in table 6. Stump height was 1.2 feet on the Lincoln National Forest, and 1. foot on the other National Forests. Methodological details can be found in appendix V Equations for predicting d.b.h. from stump diameter have been reported previously by Hann (1976).

Table 6.--*Unforked and forked tree gross cubic foot stump volume data base and regression results*

Species	National Forest	Number of trees	Regression coefficients		Relative mean squared residual (RMSQR)
			g_0	g_1	
White pine	Santa Fe, Carson	18	-2.20720716E-02	6.02924330E-03	0.0553
White pine	Lincoln	42	-9.81087640E-03	6.92301900E-03	.0159
Engelmann spruce-corkbark fir	Santa Fe, Carson	161	-1.26475621E-02	6.47928905E-03	.0658
Yellow pine	Santa Fe, Carson, Coconino, Tonto	220	-7.19317815E-02	5.21911020E-03	.0417
Yellow pine	Lincoln	11	-8.93559070E-02	6.21218970E-03	.0351
Blackjack pine	Santa Fe, Carson, Coconino, Tonto	963	-8.24872240E-03	4.87880288E-03	.0505
Blackjack pine	Lincoln	57	-3.04689829E-02	6.05850250E-03	.0268
Douglas-fir	Santa Fe, Carson, Tonto	115	7.56124690E-04	5.27297220E-03	.0648
Douglas-fir	Lincoln	93	-2.21569699E-02	6.09390425E-03	.0311
Aspen	Santa Fe, Carson	145	5.55975850E-03	5.30326265E-03	.0797
White fir	Santa Fe, Carson	66	-6.57525870E-03	5.48812315E-03	.0512
White fir	Lincoln	48	-3.25893626E-02	6.52844110E-03	.0171

Gross International 1/4-Inch Board Foot Volume--Unforked Trees

Gross International 1/4-inch board foot volume to a 6-inch top in an unforked tree is predicted by

$$V_I = V_{m(6")} \times R_{I/C}$$

where

V_I = Predicted gross International 1/4-inch board foot volume to a 6-inch top in an unforked tree

$V_{m(6")}$ = Predicted gross merchantable cubic foot volume to a 6-inch top in an unforked tree

$R_{I/C}$ = Predicted ratio of actual gross International 1/4-inch board foot volume to a 6-inch top in an unforked tree divided by predicted gross merchantable cubic foot volume to a 6-inch top in an unforked tree.

This equation was fitted using weighted least squares regression through the origin. The resulting ratio equations, $R_{I/C}$, are of the form:

$$R_{I/C} = b_0 - b_1 D^{-1} - b_2 D^{-2} - b_3 D^{-3}$$

where

D = D.b.h. in inches.

The sp-NF specific, weighted regression coefficients for $R_{I/C}$, their RMSQR, and the number of trees used can be found in table 7. The coefficient of determination, R^2, is also included to help bridge several gaps where comparable values of RMSQR were not computed. Methodological details can be found in appendix VI.

Table 7--[illegible]

Species	National forest	Number of trees	[illegible]				
ite pine	Santa Fe, Carson, Lincoln	[illegible]	[illegible]	7.52011366	[illegible]	[illegible]	[illegible]
elmann spruce-subalpine fir	[illegible]	[illegible]	[illegible]	[illegible]	-300.912806	.442404	[illegible]
llow pine	All	[illegible]	7.10051404	7.97021481	[illegible]	[illegible]	[illegible]
ackjack pine	Lincoln, Coconino, Tonto	613	[illegible]	[illegible]	221.477220	[illegible]	[illegible]
ackjack pine	[illegible]	[illegible]	7.58122078	8.51941410	[illegible]	[illegible]	[illegible]
uglas-fir	Lincoln, Tonto	[illegible]	[illegible]	.8027164	[illegible]	[illegible]	[illegible]
uglas-fir	[illegible]	[illegible]	[illegible]	.8044735	[illegible]	[illegible]	[illegible]
pen	[illegible]	[illegible]	[illegible]	-1.2768506	-4	[illegible]	[illegible]
ite fir	Lincoln	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ite fir	[illegible]	[illegible]	5.73644537	1.72093361	[illegible]	[illegible]	[illegible]

Gross International 1/4-Inch Board foot Volume--Forked Trees

The model for gross International 1/4-inch board foot volume to a 6-inch top for forked trees is

$$V_{I,f} = V_I \times R_{I,f}$$

where

$V_{I,f}$ = Predicted gross International 1/4-inch board foot volume to a 6-inch top in a forked tree

V_I = Predicted gross International 1/4-inch board foot volume to a 6-inch top in an unforked tree

$R_{I,f}$ = Predicted ratio of actual gross International 1/4-inch board foot volume to a 6-inch top in a forked tree divided by predicted gross International 1/4-inch board foot volume to a 6-inch top in an unforked tree.

The appropriate equations for $R_{I,f}$, their RMSQR, the number of trees used, and the mean, ratio $R_{I,f}$, can be found in table 8. Methodological details can be found in appendix VII

Table 8.--*Forked tree gross International 1/4-inch board foot volume data base and regression results*

Independent variables

D = D.b.h. in inches
H = Total tree height in feet
P = Height to first fork divided by H
T = 1 + (number of forks)

Species, National Forest, and regression equations	Mean $R_{I,f}$	Number of trees	Relative mean squared residual (RMSQR)
White pine on Santa Fe, Carson, and Lincoln $R_{I,f}$ = 2.21682508E-01 + 5.95430677E-05(H^2) + 2.29900234(H/D^2)	1.16873	17	.4462
Engelmann spruce-corkbark fir on Santa Fe, Carson, and Lincoln $R_{I,f}$ = 3.70906603E-01 + 7.71762038E+01($1/D^4$)	1.23734	16	.4278
or $R_{I,f}$ = -.46864127 + 1.74260009(H/D^2) + 1.46864127(P)	1.23734	16	.4154
Yellow pine on Lincoln, Coconino, Tonto, Santa Fe, and Carson $R_{I,f}$ = 1.16393889 - 2.03944633$(D/H)^2$	.95773	31	.6744
Blackjack pine on Lincoln, Coconino, and Tonto $R_{I,f}$ = 5.49502730E-01 + 1.09541429E-01(H/D)	.99776	62	.8895
or $R_{I,f}$ = .61350474 + 9.60847876E-02(H/D) - 1.52902459E-01(T) + 7.72990514E-01(P) - 3.86495257E-01(P^2)	.99776	62	.8238
Blackjack pine on Santa Fe and Carson $R_{I,f}$ = 4.15854140E-01 + 8.37338276E+01($1/D^4$)	1.03576	63	.7438
Douglas-fir on Santa Fe, Carson, and Lincoln $R_{I,f}$ = [illegible]	2.12047	20	.7158
Aspen on Santa Fe and Carson $R_{I,f}$ = [illegible]	1.08110	31	.9188
White fir on Santa Fe, Carson, and Lincoln $R_{I,f}$ = [illegible]	.95691	12	.7677
or $R_{I,f}$ = [illegible]	.95691	12	.7643

Gross Scribner Board Foot Volume--Unforked Trees

Gross Scribner board foot volume to a 6-inch top in an unforked tree is predicted by

$$V_S = V_I \times R_{S/I}$$

ere

V_S = Predicted gross Scribner board foot volume to a 6-inch top in an unforked tree

V_I = Predicted gross International board foot volume to a 6-inch top in an unforked tree

$R_{S/I}$ = Predicted ratio of actual gross Scribner board foot volume to a 6-inch top in an unforked tree divided by predicted gross International 1/4-inch board foot volume to a 6-inch top in an unforked tree.

ke International 1/4-inch board foot volume, this equation was fitted using weighted ast squares regression through the origin. The resulting ratio equations, $R_{S/I}$, are the form:

$$R_{S/I} = e_0 - e_1 D^{-1} - e_2 D^{-1.177748} - e_3 D^{-2}$$

ere

D = D.b.h. in inches.

e sp-NF specific, weighted regression coefficients for $R_{S/I}$, their RMSQR, and the mber of trees used can be found in table 9. Methodological details can be found in pendix VIII.

Table [illegible]

	National Forest	trees				
te pine	Santa Fe, Carson, Lincoln	32	1.00608606	2.384659985	0.00	
elmann spruce-corkbark fir	Santa Fe, Carson, Lincoln	71	.878453705	.00	.00	15
low pine	All	200	.982101210	.926027395	.00	14
ckjack pine	Lincoln, Coconino, Tonto		.96579222	.405679028	.66	
ckjack pine	Santa Fe, Carson	168	.993986685	1.403480122	.00	
glas-fir	Lincoln, Tonto		1.000897473	.00	4.100072359	
glas-fir	Santa Fe, Carson		.870259997	.00	.00	
en	Santa Fe, Carson		.887891	.00	.00	12
te fir	Lincoln		1.0	1.88814412	.66	
te fir	Santa Fe, Carson	31	1.01724709	1	.00	

Gross Scribner Board Foot Volume--Forked Trees

The model for gross Scribner board foot volume to a 6-inch top for forked trees is

$$V_{S,f} = V_S \times R_{S,f}$$

where

$V_{S,f}$ = Predicted gross Scribner board foot volume to a 6-inch top in a forked tree

V_S = Predicted gross Scribner board foot volume to a 6-inch top in an unforked tree, and

$R_{S,f}$ = Predicted ratio of actual gross Scribner board foot volume to a 6-inch top in a forked tree divided by predicted gross Scribner board foot volume to a 6-inch top in an unforked tree.

The appropriate equations for $R_{S,f}$, their RMSQR, the number of trees used, and the mean ratio, $R_{S,f}$, can be found in table 10. Methodological details can be found in appendix IX.

Table 10.--*Weight ratio, gross Scribner board foot volume to a 6-inch top, data base and regression results*

Independent variables

D = D.b.h. in inches
H = Total tree height in feet
P = Height to first fork divided by H
T = 1 + (number of forks)

Species, National Forest, and regression equations	Mean $R_{S,f}$	Number of trees	Relative mean squared residual (RMSQR)
White pine on Santa Fe, Carson, and Lincoln			
$R_{S,f} = 6.69426337E\text{-}01 + 1.41693541E\text{-}02(H) - 3.10631659E\text{-}02(D)$	1.00494	14	0.5093
Engelmann spruce-corkbark fir on Santa Fe, Carson, and Lincoln			
$R_{S,f} = 3.27406045E\text{-}01 + 9.24980748E+01(1/D^2)$	.98096	11	.9191
or $R_{S,f} = -0.53128818 + 2.17203301E\text{-}02(D) - 1.53128818(P^2) + 3.06257636(P)$	.98096	11	.3868
Yellow pine on Lincoln, Coconino, Tonto, Santa Fe, and Carson			
$R_{S,f} = 1.16596696 - 2.01070651(D/H)^2$	.96266	31	.7025
Blackjack pine on Santa Fe and Carson			
$R_{S,f} = 4.24761670E\text{-}01 + 1.23016529E\text{-}01(H/D)$	.86497	53	.8029
or $R_{S,f} = 6.97723772E\text{-}01 - 1.79745211E\text{-}02(D) + 8.11255589E\text{-}05(H^2) + 3.02276228E\text{-}01(P)$	.86497	53	.7426
Blackjack pine on Lincoln, Coconino, and Tonto			
$R_{S,f} = 1.50684356 - 1.94318670(D/H)$	1.00836	59	.8484
or $R_{S,f} = 5.46618888E\text{-}01 + 1.15209503E\text{-}01(H/D) - 1.75749455E\text{-}01(T) - 4.53381112E\text{-}01(P^2) + 9.06762224E\text{-}01(P)$	1.00836	59	.7476
Douglas-fir on Santa Fe, Carson, and Lincoln			
$R_{S,f} = 6.39052346E\text{-}01 + 1.18994308(H/D^2)$	.99510	17	.6622
Aspen on Santa Fe and Carson			
$R_{S,f} = 4.03747500E\text{-}01 + 1.17109771E\text{-}01(H/D)$	1.01472	15	.7935
White fir on Santa Fe, Carson, and Lincoln			
$R_{S,f} = 6.31636481E\text{-}01 + 1.50605156E\text{-}02(D)$	.93862	12	.7142

et volumes.--The general form of the net volume equations is [illegible]
pes:

$$NV = V[1.0 - (PrC \cdot FC)]$$

ere

NV = Predicted net volume of an unforked or forked tree
V = Predicted gross volume of an unforked or forked tree
PrC = Predicted probability that a tree of given characteristics will have some cull (that is, the probability that the tree will be unsound)
FC = Predicted fraction cull of a tree given that it does have some cull.

e product (PrC) (FC) estimates the average cull proportion for any tree of given char-
teristics. The advantage of separating the average cull rate into its components is
e added flexibility it provides when sampling a stand or forest. This method not only
lows the user to predict average cull proportion, but it also allows him to separate
e sampled population into completely sound and unsound trees. For example, suppose a
mple tree, X_i, represents n_i trees of the same characteristics. The values PrC and
are computed for the sample tree's characteristics and then the following estimates
e made:

$$\text{Number of sound trees} = n_i(1.0 - PrC)$$

$$\text{Number of unsound trees} = n_i(PrC)$$

$$\text{Net volume in one sound tree} = V \times (1.0)$$

$$\text{Net volume in one unsound tree} = V \times (1.0 - FC)$$

$$\text{Total net volume in sound trees} = V \times n_i(1.0 - PrC)$$

$$\text{Total net volume in unsound trees} = V \times n_i(PrC)\ (1.0 - FC)$$

ere

V = Gross volume of a tree of given characteristics.

is obvious that this kind of data provides the forest manager with much more infor-
tion concerning the structure of a population's net volume than does average cull
oportion.

As mentioned earlier, for a given species, National Forest, and volume type, the
ecific equations chosen for PrC and FC are not determined on a tree-by-tree basis,
t rather by the type of information collected during sampling. In addition to d.b.h.
d total tree height, there are two types of additional information that a user could
llect and use. One is the forking information previously discussed and the other is
formation about tree damaging agents. The specific equations chosen will depend upon
ether the user collects all, one, or none of these additional pieces of information.
ce the choice has been made, the equations will then apply to all trees, whether they
unforked, forked, undamaged, or damaged.

Probability of a Tree Being Unsound in Cubic Foot Volume--Unforked and Forked Trees

The model form for the probability of a tree being unsound in cubic foot volume to be applied to both total stem and merchantable predictions is

$$PrC_c = 1.0/(1.0 + e^{-X_c})$$

where

PrC_c = Predicted probability of a tree being unsound in cubic foot volume

X_c = A function of the tree's measured attributes.

Weighted, nonlinear regression procedures (Hamilton 1974) were used to determine the equations for X_c. The resulting equations, along with the number of trees used, are presented in table 11. An F-statistic was used to test the significance of the models. The equation for blackjack pine on the Lincoln National Forest was significant at the 95 percent level, and all other equations were significant at the 99 percent level. Methodological details can be found in appendix X.

Table 11.--*Probability of a tree being unsound in*

Independent variables

D = D.b.h. in inches H = total tree height in feet T = 1 + (number of forks)

Species, National Forest, and regression equations	
White pine on Santa Fe, Carson, and Lincoln	
$X_c = -2.955536 + 0.05898932H$	66
$X_c = -3.765521 + 0.05932042H + 0.6089821T$	66
Engelmann spruce on Santa Fe, Carson, and Lincoln	
$X_c = -1.655268 + 0.001678439DH$	136
$X_c = -2.931385 + 0.1798041D + 0.3704742T$	136
Corkbark fir on Santa Fe and Carson	
$X_c = -2.994364 + 0.3277421D$	35
$X_c = -5.310682 + 0.3746394D + 1.414157T$	35
Yellow pine on Santa Fe and Carson	
$X_c = 0.9767974 + 0.03559618D$	53
Yellow pine on Lincoln, Coconino, and Tonto	
$X_c = 0.3547862 + 0.003783644D$	179
Blackjack pine on Coconino	
$X_c = -5.640547 + 0.04713862H$	306
$X_c = -6.206244 + 0.04502878H + 0.6055332T$	306
Blackjack pine on Lincoln	
$X_c = -2.672635 + 0.05792241H$	57
Blackjack pine on Tonto	
$X_c = -4.768802 + 0.2093156D$	380
Blackjack pine on Santa Fe and Carson	
$X_c = -1.418322 + 0.00006223427D^2H$	283
$X_c = -3.627838 + 0.1540565D + 0.6277967T$	283
Douglas fir on Lincoln and Tonto	
$X_c = -1.606318 + 0.0008139147DH$	114
Douglas-fir on Santa Fe and Carson	
$X_c = -2.591351 + 0.1359878D$	96
$X_c = -2.919862 + 0.001301024DH + 0.8573843T$	96
Aspen on Santa Fe and Carson	
$X_c = 1.202390 + 0.2220774D$	146
White fir on Lincoln	
$X_c = -1.730640 + 0.1221281D$	48
White fir on Santa Fe and Carson	
$X_c = -3.118569 + 0.04665243H$	66

Fraction Cull in Total Stem Cubic Foot Volume Given the Tree is Unsound--Unforked and Forked Trees

To predict the fraction of an unsound tree's total stem cubic foot volume that is in cull, the following functional relationship is used:

$$FC_t = h_t(1.0 - e^{Y_t})$$

where

FC_t = Predicted fraction cull in total stem cubic foot volume given the tree is unsound

h_t = a constant

Y_t = A function of the tree's measured attributes.

The sp-NF specific values and functions of h_t and Y_t, respectively, the number of trees used, and the resulting RMSQR values are found in table 12. An examination of the RMSQR values indicate that many of the equations might not reduce the squared deviations more than a mean value of FC_t. This is due both to the general difficulty of modeling cull rates and to the relatively small number of sample trees with cull. It is felt, however, that the equations do represent cull trends in at least the sample trees and that they also seem to behave reasonably well. It is recommended, therefore, that the equations be used but, for those who choose not to do so, mean values of FC_t have also been included in table 12. Methodological details can be found in appendix XI.

[illegible]

Independent Variables:
D = D.b.h. in inches H = Total tree height in feet

Species, National Forest, and regressi[illegible]	Mean [illegible]	Number of trees	Relative mean squared residual (RMSQR)
White pine on Santa Fe, Carson, and Lincoln			
h_t = [illegible]			
Y_t = [illegible]	0.14358	34	[illegible]
Engelmann spruce on Santa Fe, Carson, and Lincoln			
Y_t = -3.01894250E-01 + 4.30560743E-03(H) -6.43668344E-04(D^2)	[illegible]	44	[illegible]
Corkbark fir on Santa Fe and Carson			
h_t = 0.961637598			
Y_t = 1.36557290E-01 - 5.67626653E-02($\frac{H}{D}$)	.09807	21	[illegible]
Yellow pine on Lincoln, Coconino, Tonto, Santa Fe, and Carson			
Y_t = (-1.63671565E-01) + (3.25503506E-05)DH	.09303	154	[illegible]
Blackjack pine on Lincoln, Coconino, and Tonto			
Y_t = (-9.71749091E-03) - (6.33508782E-07)D^2H	.01878	80	.9364
Blackjack pine on Santa Fe and Carson			
Y_t = [illegible]	.04676	90	[illegible]
Douglas-fir on Santa Fe, Carson, Lincoln, and Tonto			
Y_t = (-2.74212212E-01) - (6.75308810E-06)D^2H	.08489	66	.9818
Aspen on Santa Fe and Carson			
Y_t = (-2.1547562E-01) - (9.32233189E-03)D^2 + (1.31076200E-03)DH	.28482	139	.7441
White fir on Santa Fe, Carson, and Lincoln			
h_t = 0.440697488			
Y_t = [illegible]	.15895	51	.7790

ction Cull in Merchantable Cubic Foot Volume Given the Tree Is Unsound--Unforked and rked Trees

The following model form is used to predict the fraction of an unsound tree's mer-ntable cubic foot volume that is cull:

$$FC_m = h_m(1.0 - e^{Y_m})$$

re

FC_m = Predicted fraction cull in merchantable cubic foot volume to a specified top diameter given the tree is unsound

h_m = A constant

Y_m = A function of the tree's attributes and a specified top diameter between 3 and 8 inches, inside bark.

appropriate values of h_m and functions for Y_m, the number of observations used, and resulting RMSQR values are found in table 13. While these models are recommended use, equations predicting mean FC_m as a function of top diameter are also included table 13 for those who choose not to use the FC_m equations. Methodological details be found in appendix XII.

Table 13.--*Fraction cull in merchantable cubic foot volume, given the tree is unsound, data base, and regression results*

Independent variables

D = D.b.h. in inches D_m = Top diameter, inside bark, in inches

H = Total tree height in feet

Species, National Forest, and regression equations	Number of observations	Relative mean squared residual (RMSQR)
White pine on Santa Fe, Carson, and Lincoln		
$h_m = 0.525456732$		
$Y_m = j_1 D^2$	204	0.8386
or $j_1 = -7.62194840E-04 - 1.72E-10D_m^7$		
$FC_m = 0.139967204 + 1.40417133E-07D_m^5$		
Engelmann spruce on Santa Fe, Carson, and Lincoln		
$h_m = 0.809722162$		
$Y_m = j_0 + j_1 H + j_2 D^2$	246	.8881
$j_0 = -4.79663334E-01$		
$j_1 = 5.99578762E-03$		
or $j_2 = -3.54716909E-04 - 2.30591722E-05D_m$		
$FC_m = 1.10092261E-01 + 4.70167336E-04D_m^4$		
$-8.80762813E-05D_m^5 + 4.83607897E-07D_m^7$		
Corkbark fir on Santa Fe and Carson		
$h_m = 0.945856475$		
$Y_m = j_0 + j_1 H/D$	120	.8010
$j_0 = -2.04082904E-02 + 4.51477415E-02D_m$		
or $j_1 = -1.16845115E-02 - 1.29460840E-02D_m$		
$FC_m = 7.39331940E-02 + 6.95210968E-03D_m$		
Yellow pine on Lincoln, Coconino, Tonto, Santa Fe, and Carson		
$h_m = 0.912935298$		
$Y_m = j_0 + j_1 DH$	924	.9696
$j_0 = -1.67513064E-01 - 2.39E-07D_m^5$		
or $j_1 = 3.368982527E-05 + 8.684E-11D_m^5$		
$FC_m = 9.41334189E-02 + 4.35158264E-06D_m^3$		
Blackjack pine on Lincoln, Coconino, and Tonto		
$h_m = 0.294142214$		
$Y_m = j_0 + j_1 D^2 H$	475	.9351
$j_0 = -3.39989415E-02 + 1.48516345E-04D_m^2$		
or $j_1 = -2.19796372E-06 - 8.55224950E-09D_m^2$		
$FC_m = 1.92501222E-02$		

(con.)

Table 13.--*(con.)*

Species, National Forest, and regression equations	of observations	mean squared
Blackjack pine on Santa Fe and Carson		
h_m = 0.943058463		
Y_m = β_0 + β_1H/D	532	0.984
β_0 = -1.80176132E-02 - 1.62628643E-06D^6		
+ 2.00018357E-07D^7		
β_1 = -9.68124280E-02 + 6.49858343E-06D^5		
-8.00723544E-07D^6		
or		
FC_m = 4.19699099E-02 + 1.20336014E-05D^5		
-3.54771919E-06D^6 + 2.55488876E-07D^7		
Douglas-fir on Santa Fe, Lincoln, and Tonto		
h_m = 0.243391121		
Y_m = β_0 + β_1D H	390	.9785
β_0 = -2.80555445E-01 - 1.2792366E-06D		
+ 1.24888494E-07D^2		
or β_1 = -5.87585480E-06 + 8.02594124E-11D^4		
FC_m = 7.88426507E-02 + 4.88150784E-05D^3		
Aspen on Santa Fe and Carson		
h_m = 0.881568806		
Y_m = β_0 + β_1D + β_2H	682	.7639
β_0 = 1.77859273 - 1.93330892D^6 ·		
+ 4.42422923E-01D_m		
β_1 = -9.36182562E-03 + 2.23064483E-08D^6		
-3.90157892E-09D_m		
or β_2 = 1.38034680E-03 + 9.42523449E-11D^7		
FC_m = 2.87277280E-01 + 5.42205159E-04$D_m^{2.5}$		
White fir on Santa Fe, Carson, and Lincoln		
h_m = 0.438946854		
Y_m = β_1D	301	.8046
β_1 = -1.211898445E-03 - 9.066E-09D^4		
or		
FC_m = 1.54156056E-01 + 8.17555326E-06D^4		

Probability of a Tree Being Unsound in Board Foot Volume--Unforked and Forked Trees

The probability of a tree being unsound in board foot volume, to be applied to both International 1/4-inch and Scribner board foot predictions, is predicted by

$$PrC_B = 1.0/(1.0 + e^{-X_B})$$

where

PrC_B = Predicted probability of a tree being unsound in board foot volume

X_B = A function of d.b.h., total tree height, number of tree tips, and the presence or absence of significant damage.

The equations for X_B were also fitted using weighted, nonlinear regression procedures, and the results are given in table 14, along with the number of trees used. Again, the equation for blackjack pine on the Lincoln National Forest proved to be significant at the 95 percent level, whereas all the other equations were significant at the 99 percent level.

Two damaging agents, sweep (or crook) and porcupine, proved to be useful in predicting whether a tree was sound or not. A damaging agent is recorded only if it is severe enough to (1) prevent the tree from surviving; (2) preclude the production of a marketable product; or (3) diminish the quality or quantity of that product. Damage is entered into the equations through the usage of dummy variable(s). If the tree has the particular damage, the dummy variable is set to 1.0, otherwise it is 0. Only one damaging agent is recorded per tree, and, therefore, equations with two or more dummy variables in them would have at most only one of them set to 1.0 and the rest to 0. Methodological details can be found in appendix XIII.

Table 14.--*Probability of [illegible] board foot volume--regression results*

Independent variables

D = D.b.h. in inches H = total tree height in feet T = 1 + (number of forks)
S = 1.0 Tree with sweep or crook Pd = 1.0 Tree with porcupine damage
0.0 Tree with no sweep or crook = 0.0 Tree with no porcupine damage

Species, National Forest, and regression equations	Number of
White pine on Santa Fe, Carson, and Lincoln	
$X_B = -4.421720 + 0.1001612H$	56
Engelmann spruce on Santa Fe, Carson, and Lincoln	
$X_B = -2.057921 + 0.1664132D$	103
or	
$X_B = -2.412705 + 0.1689685D + 0.2973478T$	[illegible]
Corkbark fir on Santa Fe and Carson	
$X_B = -2.724328 + 0.3295897D$	31
Yellow pine on Santa Fe and Carson	
$X_B = 1.416597 + 0.08953296D$	53
Yellow pine on Lincoln, Coconino, and Tonto	
$X_B = -0.3255527 + 0.09002528D$	179
Blackjack pine on Coconino	
$X_B = -3.790069 + 0.002540676DH$	260
Blackjack pine on Lincoln	
$X_B = -1.195571 + 0.03548680H$	49
Blackjack pine on Tonto	
$X_B = -4.866131 + 0.06649043H$	320
Blackjack pine on Santa Fe and Carson	
$X_B = -3.023414 + 0.05290037H$	271
or $X_B = -3.551965 + 0.1806999D + 0.6451722T$	271
or $X_B = -3.650835 + 0.06016044H + 1.278169(Pd) + 1.785158S$	271
or $X_B = -3.625993 + 0.1844583D + 0.5517561T + 1.474701S$	271
Douglas fir on Lincoln and Tonto	
$X_B = -4.201783 + 0.3419626D$	106
Douglas-fir on Santa Fe and Carson	
$X_B = -1.185559 + 0.0001857571D^2H$	84
or $X_B = -1.363273 + 0.0001709440D^2H + 2.305584S$	[illegible]
Aspen on Santa Fe and Carson	
$X_B = -3.889285 + 0.9000166D$	119
White fir on Lincoln	
$X_B = -2.260617 + 0.05019542H$	45
White fir on Santa Fe and Carson	
X_B -2.955732 + 0.2320741D	54
$X_B = -3.023744 + 0.2225154D + 1.260367S$	[illegible]

Fraction Cull in International 1/4-Inch Board Foot Volume Given the Tree Is Unsound--Unforked and Forked Trees

To predict the fraction of an unsound tree's International 1/4-inch board foot volume that is in cull, the following model is used:

$$FC_I = h_I(e^{Y_I})$$

where

FC_I = Predicted fraction cull in International 1/4-inch board foot volume to a 6-inch top given the tree is unsound

h_I = A constant

Y_I = A function of the tree's attributes.

The sp-NF specific values and functions of h_I and Y_I, respectively, the number of trees used, and the resulting RMSQR values are found in table 15. The models for Engelmann spruce and corkbark fir were too poor to be useful and, therefore, only their mean FC_I values are included. Mean values of FC_I for the other sp-NF combinations are also found in table 15. Methodological details can be found in appendix XIV.

Table 15.--*Fraction cull in International 1/4-inch board foot volume, given the tree is unsound, data base, and regression results*

Independent variables
D = D.b.h. in inches H = Total tree height in feet

Species, National Forest, and regression results	Mean FC_I	Number of trees	Relative mean squared residual (RMSQR)
White pine on Santa Fe, Carson, and Lincoln			
h_I = 0.181977197			
Y_I = 9.53653005E-04(D^2)	0.30592	39	0.9776
Engelmann spruce on Santa Fe, Carson, and Lincoln			
No model--Use mean FC_I	.41094	45	--
Corkbark fir on Santa Fe and Carson			
No model--Use mean FC_I	.55402	21	--
Yellow pine on Santa Fe, Carson, Lincoln, Coconino, and Tonto			
h_I = 1.05452734			
Y_I = -1.89706097E-02(H)	.28490	202	.9199
Blackjack pine on Lincoln, Coconino, and Tonto			
h_I = 0.420800123			
Y_I = -1.74436591E-02(H)	.15676	138	.9430
Blackjack pine on Santa Fe and Carson			
h_I = 0.467888236			
Y_I = -1.89407426E-01(H/D)	.22145	114	.9992
Douglas-fir on Santa Fe, Carson, Lincoln, and Tonto			
h_I = 0.839814911			
Y_I = -2.92010520E-01(H/D)	.26258	116	.9479
Aspen on Santa Fe and Carson			
h_I = 1.39801055			
Y_I = -8.79518535E-03(H)	.89429	114	.9364
White fir on Santa Fe, Carson, and Lincoln			
h_I = 0.251235533			
Y_I = 5.01411097E-06(D^2H)	.34497	62	.9972

...action Cull in Scribner Board Foot Volume of ...rked Trees

The following model form is used to predict the fraction of an unsound tree's ribner board foot volume that is cull:

$$FC_S = h_S(e^{Y_S})$$

ere

FC_S = Predicted fraction cull in Scribner board foot volume to a 6-inch top given the tree is unsound

h_S = A constant

Y_S = A function of the tree's attributes.

e appropriate values of h_S and functions for Y_S, respectively, the number of trees ed, and the resulting RMSQR values are found in table 16. Again, the models for gelmann spruce and corkbark fir were too poor to be useful and, therefore, only their an FC_S values are included. Several other models proved to be no better than the mean the user may also want to use the mean FC_S values in table 16 rather than the models. thodological details can be found in appendix XV.

...ble 16.--...

Independent variables
D = D.b.h. in inches H = Total tree height in feet

Species, National Forest, and regression results	Mean	Number of trees	Relative mean squared residual (RMSQR)
...te pine on Santa Fe, Carson, and Lincoln			
h_S = 0.24546450			
Y_S = 9.55078847E-04(D^2)	0.41683	39	1.0027
...elmann spruce on Santa Fe, Carson, and Lincoln			
No model--Use mean FC_S	.42864	45	
...rkbark fir on Santa Fe and Carson			
No model--Use mean FC_S	.57057	21	
...llow pine on Santa Fe, Carson, Lincoln, Coconino, and Tonto			
h_S = 1.38266375			
Y_S = -1.94422273E-02(H)	.36288	202	.9928
...ckjack pine on Lincoln, Coconino, and Tonto			
h_S = 0.617372520			
Y_S = -1.96681561E-02(H)			
...ckjack pine on Santa Fe and Carson			
h_S = 0.646540139			
Y_S = -2.20260760E-01(H/D)			
...glas-fir on Santa Fe, Carson, Lincoln, and Tonto			
h_S = 1.24325723			
Y_S = -3.45196887E-01(H/D)	.31653	116	.9126
...en on Santa Fe and Carson			
h_S = 1.23056500			
Y_S = -5.46784441E-03(H)			
...te fir on Santa Fe, Carson, and Lincoln			
h_S = 0.294076429			
Y_S = 4.60611418E-06(D^2H)	.39036	62	1.0026

DISCUSSION AND CONCLUSIONS

A summary of the methodology for predicting the various volume types is given in table 17. The advantage of this approach to developing volume equations is that it avoids or eliminates many of the problems of consistency, compatibility, reliability, and flexibility found with previous sets of volume equations. The disadvantage is that the method does not lend itself well to hand computations of tree volumes. To minimize this problem, we have prepared volume tables for unforked trees ("Comprehensive tree volume equations for major species of New Mexico and Arizona: II. Tables for unforked trees"). For those with access to a computer, a FORTRAN subroutine has been written and can be obtained in versions for the CDC 6400 or the UNIVAC 1108 by writing:

Southwest Volume Subroutine
Forest and Range Evaluation Unit
Intermountain Forest and Range Experiment Station
507 - 25th Street
Ogden, Utah 84401

Table 17.--*Summary of methodology for predicting various tree volume types*

Predicted value	Method for prediction
Total stem gross cubic foot volume, unforked trees	V_t
Total stem gross cubic foot volume, forked trees	$V_{t,f} = V_t \times R_{t,f}$
Merchantable gross cubic foot volume, unforked trees	$V_m = V_t - V_u$
Merchantable gross cubic foot volume, forked trees	$V_{m,f} = V_m \times R_{m,f}$
Gross International 1/4-inch board foot volume, unforked trees	$V_I = V_m(6") \times R_{I/c}$
Gross International 1/4-inch board foot volume, forked trees	$V_{I,f} = V_I \times R_{I,f}$
Gross Scribner board foot volume, unforked trees	$V_S = V_I \times R_{S/I}$
Gross Scribner board foot volume, forked trees	$V_{S,f} = V_S \times R_{S,f}$
Total stem net cubic foot volume, unforked trees	$NV_t = V_t \times [1 - (PrC_c \times FC_t)]$
Total stem net cubic foot volume, forked trees	$NV_{t,f} = V_{t,f} \times [1 - (PrC_c \times FC_t)]$
Merchantable net cubic foot volume, unforked trees	$NV_m = V_m \times [1 - (PrC_c \times FC_m)]$
Merchantable net cubic foot volume, forked trees	$NV_{m,f} = V_{m,f} \times [1 - (PrC_c \times FC_m)]$
Net International 1/4-inch board-foot volume, unforked trees	$NV_I = V_I \times [1 - (PrC_B \times FC_I)]$
Net International 1/4-inch board foot volume, forked trees	$NV_{I,f} = V_{I,f} \times [1 - (PrC_B \times FC_I)]$
Net Scribner board foot volume, unforked trees	$NV_S = V_S \times [1 - (PrC_B \times FC_S)]$
Net Scribner board foot volume, forked trees	$NV_{S,f} = V_{S,f} \times [1 - (PrC_B \times FC_S)]$

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APPENDIXES

Details of Methodology

1. [illegible] Trees

The basic model of

$$V_t = a_0 + a_1 D^2 H \qquad (1$$

where

V_t = Predicted total stem gross cubic foot volume in an unforked tree

D = D.b.h. in inches

H = Total tree height in feet

has been used for years for predicting total stem gross cubic foot volume (Husch 1963). Weighting this model by

$$W = (D^2 H)^{-2} \qquad (2$$

was suggested by Cunia (1964) as a means for homogenizing the variance about regressio This model and weighting procedure was applied to each sp-NF combination and a plot of residuals indicated that the variance was homogenized by the weighting. However, Pearson's beta statistics computed for each equation indicated that the residuals were not normally distributed. This problem precluded the usage of this model for testing the possibility of combining species across National Forests or of combining some of the species with others, using analysis of covariance.

It was then hypothesized that the following model might eliminate the problem:

$$\ln(V_t) = a_0 + a_1 \ln(H) + a_2 \ln(D). \qquad (3$$

The plots of residuals again confirmed that variance was homogenized and Pearson's bet statistics this time indicated that the residuals were closer to being normally distri buted. Analysis of covariance was then applied to see if species could be combined across forests. The results indicated that blackjack pine, Douglas-fir, and white fir on the Santa Fe and Carson National Forests could not be combined with the same specie on the other National Forests. All other species were combined across Forests.

Only two "species" combinations were tested. One was whether yellow pine and blackjack pine could be combined. Results of the testing indicated that they could no be combined, a conclusion supported by the findings of Hornibrook (1936) and Myers (1963). The other combination tested was Engelmann spruce with corkbark fir. This test was made because of the small data set for corkbark fir. This test resulted in the combining of Engelmann spruce with corkbark fir.

These final data sets were fitted to equation (1) using weighted least squares regression. For aspen, this resulted in a negative intercept. Therefore, an intercep value of 0.0327 (the volume of a tree 2 inches in diameter at the root collar and 4.5 feet tall, assuming conical shape) was forced on the equation instead of forcing it through the origin.

All final equations were visually checked by plotting the predicted and actual volumes over diameter by height classes.

The ratios of actual forked volume divided by predicted unforked volume were
otted over d.b.h. (D), total tree height (H), position to fork (P), and number of fo
) and examined for trends. From this examination, a set of 12 potential transforma
ons on D, H, P, and T were developed and all possible combinations of three or less
re screened through program REX (Grosenbaugh 1967). Selected models from this screen
g run were then tabled and the one with the lowest RMSQR that "behaved well" was
cked as the final model. (An equation was judged to "behave well" if it did not
oduce unrealistic results over the expected range of usage and if it did not exhibit
undulating behavior for different combinations of tree characteristics.) Yellow
s combined with blackjack pine, and white fir and Douglas-fir were pooled across
tional Forests because of the need to strengthen the data sets.

I. Merchantable Gross Cubic Foot Volume--Unforked Trees

Expressing merchantable gross cubic foot volume as the difference between total
em gross cubic foot volume and the unmerchantable gross cubic foot volume in the top
d stump is a convenient technique for examining and then characterizing the effect of
anging top diameter upon merchantable gross cubic foot volume. To see this advantage,
nsider the following:

Unmerchantable Volume = (Top Volume) + (Stump Volume)

$$= \left(\frac{k \cdot \pi}{4 \cdot 144}\right) \left(\begin{matrix}\text{Top Diameter} \\ \text{in Inches}\end{matrix}\right)^2 \left(\begin{matrix}\text{Top Height} \\ \text{in Feet}\end{matrix}\right)$$

$$+ \left(\frac{\pi}{4 \cdot 144}\right) \left(\begin{matrix}\text{Stump Diameter} \\ \text{in Inches}\end{matrix}\right)^2 \left(\begin{matrix}\text{Stump Height} \\ \text{in Feet}\end{matrix}\right) \qquad (4)$$

ere

k = A form factor.

has been shown that stump diameter and d.b.h. are highly correlated (Hann 1976) and
is also true that stump height is basically a constant; therefore, the second term
equation (4) can be expressed as

$$+ b_0 .$$

r top volume, the top diameter is specified by the user; therefore, the unknown quan-
ties are top length and the form factor, k. To help determine the relationship of top
ngth to d.b.h. and total tree height, the following model was fitted for each top
ameter:

$$\ln(TL) = a_0 + a_1 \ln(D) + a_2 \ln(H)$$

ere

TL = Top length in feet.

By examining the behavior of the coefficients across the various top diameter, it was found that the model

$$TL = a_1 D_m \frac{H}{D^n} \tag{7}$$

where

D_m = Top diameter inside bark, in inches

n = An sp-NF specific value of 1.0, 1.5, or 2.0

was applicable. This model assumes that the top can be approximated by a conic form (Gray 1956; Husch 1963; and Assman 1970). The power on d.b.h., n, can be thought of as determining the diameter of the top cone projected to ground level. This is because total tree height is measured as the distance from the ground level to the tip of the tree and consequently the relationship

$$\frac{TL}{D_m} = a_1 \frac{H}{D^n} \tag{8}$$

will hold for similar triangles only if D^n is directly proportional to diameter at ground level.

With this background as a basis, the model for unmerchantable volume is therefore:

$$V_u = b_0 + b_1 D_m^3 \frac{H}{D^n} + b_2 D^2 \tag{9}$$

where

V_u = Gross cubic foot volume in the top and stump for a specified top diameter.

Analysis of residuals indicated that weighting was necessary to homogenize variance. A procedure described by Hann and McKinney (1975) was therefore used to obtain the weight:

$$W = \left[\frac{D_m^3 H}{D^n}\right]^{-1} = \frac{D^n}{D_m^3 H} . \tag{10}$$

Weighted least squares regression was used on each sp-NF combination to obtain the regression coefficients for n equal to 1.0, 1.5, and 2.0. The final regression equatio was that which minimized RMSQR. Further refinement for a value of n was not necessary because of the small differences in the RMSQR values of the three values tested. The final merchantable gross cubic foot volume equations were visually checked by plotting the data points versus representative curves from the equations over diameter by height classes.

A word of caution concerning the interpretation of the terms in this model is appropriate. While the logic behind the two components is clear, the final equations cannot be divided into components because of multicollinearity between the two (Kmenta 1971). This can be seen by comparing the second component of the unmerchantable model to the model derived separately for stump volume. The coefficients are in the same proximity but are not equal. However, the presence of multicollinearity, so long as it is not perfect, does not bias the estimation of unmerchantable volume (Kmenta 1971).

Merchantable Gross Cubic Foot Volume--Forked Trees

To maintain consistency across top diameters, the same model used in predicting
al stem gross cubic foot volume was fitted to each top diameter data set. The
ulting regression coefficients were examined for trends over top diameter. From this
nination, the regression coefficients were modeled as linear functions of top diam-
r. The basic model with the coefficients as functions of top diameter was then
ted to the whole data set for a final overall slope correction on the model. Models
h forking variables that proved not to be better than models without forking vari-
es were dropped.

Because the RMSQR values of the models were high, it was decided to provide an
ional model that would predict the mean ratio as a function of just top diameter.
do this, the mean ratio values for the six top diameters were weighted by their
pective number of observations and then screened against 12 power transformations
top diameter. Selected models were then examined for reasonableness of behavior and
one that behaved both reasonably and minimized RMSQR was picked as the final model.

Gross Cubic Foot Stump Volume--Unforked and Forked Trees

The basic model:

$$V_{st} = a_0 + a_1 D^2 \qquad (11$$

re

V_{st} = Gross volume of the stump in cubic feet

fitted to the separate sp-NF combinations. The residuals were plotted and they
ealed that the basic model was appropriate but that the variance increased with the
are of D^2. Therefore, the model was refitted using a weight of

$$W = D^{-}. \qquad (12$$

residuals were plotted and this time they were homogeneous.

Analysis of covariance was then used to determine if species could be combined
oss all National Forests except the Lincoln, where stump height was 1.2 feet instead
the standard of 1.0 foot. The results indicated that they could be so combined.
lysis of covariance was also used to check to see if Engelmann spruce and corkbark
could still be legitimately combined, and the results indicated that they could.

Gross International 1/4-Inch Board Foot Volume--Unforked Trees

The approach of modeling the ratio of gross International 1/4-inch board foot
ume to a 6-inch top divided by the gross merchantable cubic foot volume to a 6-inch
was used to provide the needed control on the behavior of the International 1/4-inch
el. It has long been recognized that this ratio starts with a zero value at a d.b.h.
r 6 inches and increases monotonically, as d.b.h. increases, to an asymptotic ratio
ue between 6 and 8 (Husch 1963; Avery 1967). It has also been shown that this ratio
be affected by tree height as well (Husch 1963).

With this in mind, two models were hypothesized for trial:

$$R_{I/C} = a_0 - a_1 H/D - a_2 H/(D^2) \quad (13)$$

$$R_{I/C} = b_0 - b_1 D^{-1} - a_2 D^{-2} \quad (14)$$

where

$R_{I/C}$ = Ratio of actual gross International 1/4-inch board foot volume to a 6-inch top divided by predicted gross merchantable cubic foot volume to a 6-inch top in an unforked tree.

The signs on the coefficients a_1, a_2, and b_1, b_2 must be positive for the model to behave as expected.

Before these models were tried, the ratio values were formed for all trees 6.1 inches and larger and plotted for the sp-NF combinations previously delineated. An examination of these plots resulted in the decision to combine blackjack pine data sets with the yellow pine data sets and to combine both Douglas-fir data sets. The plots also showed a few outliers that were eliminated from the appropriate data sets.

The two models, (13) and (14), were then fitted to the data sets to determine whic of the two minimized RMSQR. The model with tree height (13) proved to be the worst and therefore, was eliminated. The fits for model (14) were reasonable for only the ponderosa pine and the Douglas-fir data sets. The other data sets either had a negativ sign on b_1 or b_2 or the plots of data sets versus the predicted curves indicated a poor fit. The ponderosa pine model was then "forced" onto the white pine and the white fir on the Lincoln National Forest data sets with good results. This was done by scaling the ponderosa pine model through an overall slope correction using least squares regres sion. Techniques similar to those described by Jensen (1964, 1973, and 1976) and Jense and Homeyer (1970 and 1971) were used to develop better behaved (within a reasonable usage range) ratio models for Engelmann spruce-corkbark fir, aspen, and white fir on the Santa Fe and Carson National Forests data sets.

The resulting model form for white fir was the same as model (14) but, of course, these parameter estimates are not least squares estimates in this case. The form of the models for aspen and Engelmann spruce-corkbark fir was:

$$R_{I/C} = c_0 - c_1 D^{-1} - c_2 D^{-2} - c_3 D^{-3}. \quad (15)$$

For both species groups, at least one of the parameters was negative which resulted in an undesirable "peak" and "valley" in the ratio equation outside the available data range. For aspen, the undesirable points also occurred outside the reasonable usage range, but for Engelmann spruce-corkbark fir, the points did occur within the reasonabl usage range. Fortunately, the magnitudes of the "peak" and "valley" were small and it was felt that they would not cause serious problems when predicting International 1/4-inch board foot volume.

The appropriate ratio models were then multiplied by their predicted merchantable cubic foot volume to a 6-inch top for each sp-NF combination and then fitted to actual International 1/4-inch board foot volume to a 6-inch top, using least squares regressio through the origin to provide a slope correction. The resulting basic model form and its error structure, therefore, is the following:

$$V_I = a_1 * (R_{I/C}) \times (V_{m(6")}) + \varepsilon \quad (16)$$

ere

V_I = Predicted gross International 1/4-inch board foot volume to a 6-inch top

$V_{m(6")}$ = Predicted gross merchantable cubic foot volume to a 6-inch top

d_1 = Least squares regression coefficient

ε = Residual about regression.

Next, the necessity for weighting this model was examined through the procedure scribed by Hann and McKinney (1975). This resulted in weights being formed of the pe:

$$W = (D^{e_1} H^{e_2} V_I^{e_3})^{-1}.$$

fortunately, no common set of values e_1, e_2, and e_3 could be found for all sp-NF mbinations. The final sp-NF weights were used in weighted least squares regression rough the origin to obtain the final slope correction. These slope corrections were en incorporated into the ratio models by multiplication. As a final check, the data nts and regression equations were plotted over d.b.h. and total tree height to ermine adequacy of fit.

When considering this approach to modeling International 1/4-inch board foot ume, the basic model form of equation (16) must be kept in mind. If a set of pro-sed ratio equations had been available, then the fitting of equation (16) could have en done by screening the various ratio equations times cubic foot volume to determine ch was appropriate for the sp-NF combination. Unfortunately, a proposed set of ratio nations was not available; therefore, the ratio equations had to be developed using same data set.

There is a tendency to think that what is really being fitted is the model involv-the 11 to 15 independent variables that would be formed by multiplying the ratio merchantable cubic foot volume models together. Using this approach, it was found t some independent variables proved to be insignificant while the signs and gnitude of other regression coefficients changed because of multicollinearity blems. The result was an equation with all of the undesirable properties that e to be avoided. The approach adopted here produces a model that behaves in a rea-nable and consistent fashion, but sacrifices some statistical niceties.

. Gross International 1/4-Inch Board Foot Volume--Forked Trees

The method used to determine the ratio correction for forking upon International -inch board foot volume was the same as that used to develop the equations for fork-g in total stem gross cubic foot volume. All selected equations were tabulated and ecked for reasonableness. From this it was discovered that the Douglas-fir equation l not behave as expected. Therefore, the following power model was fitted to Douglas-r:

$$\ln (R_{I,f}) = \gamma_0 + \gamma_1 H$$

ere

$R_{I,f}$ = Predicted ratio of actual gross International 1/4-inch board foot volume to a 6-inch top in a forked tree divided by predicted International 1/4-inch board foot volume to a 6-inch top in an unforked tree.

This was transformed back by taking the antilog of both sides and a least squares slope correction was made on the resulting model to correct it for possible log bias. Tabulation of this model showed that it did behave reasonably.

VIII. Gross Scribner Board Foot Volume--Unforked Trees

As described by Avery (1967), the ratio of Scribner board foot volume divided by International board foot volume starts well below 1.0 at small diameters and then increases monotonically toward an asymptotic value of 1 as diameter increases. This relationship can be expressed as

$$R_{S/I} = a_0 - a_1 D^{-1} - a_2 D^{-2} \quad (19)$$

where

$R_{S/I}$ = Predicted ratio of actual gross Scribner board foot volume to a 6-inch top divided by predicted gross International 1/4-inch board foot volume to a 6-inch top.

The signs on a_1 and a_2 must be positive and a_0 must be near 1 for the model to behave reasonably.

Individual values of $R_{S/I}$ were formed and plotted across d.b.h. for all sp-NF combinations used in gross cubic foot equation development. All data below 9 inches d.b.h. and certain outliers were eliminated based on the results of the plots. This was necessary because the ratio values below 9 inches started to turn upward and exceed 1 as d.b.h. decreased. This problem was attributed to the way in which Scribner volume is estimated in program NETVSL. The elimination of trees under 9 inches should not cause problems because Scribner volume is seldom computed for trees under that limit.

Equation (19) was fitted to the corrected data set. Weights were developed using the basic model:

$$V_S = b_1 \times (R_{S/I}) \times (V_I) + \varepsilon \quad (20)$$

where

V_S = Predicted gross Scribner board foot volume to a 6-inch top

b_1 = Least squares regression coefficient

ε = Residual about regression

and the same process as described for International 1/4-inch board foot volume. An examination of the final weighted least squares regression coefficients, after the slope correction was multiplied through the ratio model, revealed that only the models for yellow pine, both blackjack pines, and white fir on the Santa Fe and Carson National Forests were reasonable.

An abbreviated ratio model:

$$R_{S/I} = c_0 - c_1 D^{-2} \quad (21)$$

was then tried using the same weighted scheme as previously described. This model proved reasonable for Engelmann spruce-corkbark fir, aspen, and Douglas-fir on the San Fe and Carson National Forests.

A model of the form:

$$\ln (1.0 - R_{S/I}) = \beta_0 + \beta_1 \ln$$

as then tried on the remaining data sets to determine the power in the model:

$$R_{S/I} = \beta_0 - \beta_1 D^{-1}$$

his was also weighted and proved reasonable for Douglas-fir on the Coconino, Tonto, nd Lincoln National Forests.

Both white pine and white fir on the Lincoln National Forest proved to be particularly troublesome, with all previous attempts failing to provide a reasonable model. n order to force a reasonable model on these two data sets, the following model was tted:

$$1.0 - R_{S/I} = \beta_0 D^{-1} + \beta_1 D^{-2}$$

his was then transformed to

$$R_{S/I} = 1.0 - \beta_0 D^{-1} - \beta_1 D^{-2}.$$

odel (25) could not be corrected with a weighted slope because doing so caused the itercept to exceed 1.

Again, all final models, with the final slope correction multiplied into them, were ecked by plotting. The caution given in the section on gross International 1/4-inch ard foot volume for unforked trees concerning the interpretation of this approach plies even more strongly here. In this case, if all of the model components were ltiplied out, there would be from 23 to 63 independent variables to fit and the result ould be even more unreasonable than in the International 1/4-inch board foot volume se.

L. Gross Scribner Board Foot Volume--Forked Trees

The techniques used were the same as for International 1/4-inch board foot volume forked trees. In this case, however, the basic model for Douglas-fir behaved reasonly so no special effort was necessary to model it.

X Probability of a Tree Being Unsound in Cubic Foot Volume--Unforked and Forked Trees

By definition, the probability of a tree being unsound must take on a value between and 1. A form that constrains itself between these two values is the logistic nction:

$$PrC_c = 1.0/(1.0 + e^{-X_c}) \qquad (26)$$

ere

PrC_c = Predicted probability of a tree being unsound in total stem and in merchantable cubic foot volume

X_c = A function of the tree's measured attributes.

ilton (1974) developed program RISK to fit this function to a dichotomous dependent iable. The approach basically uses the first degree term of the Taylor Series expanon of the function in weighted nonlinear regression. Output, in part, consists of e regression coefficients, an F-statistic that tests the significance of the

model, t-statistics which test the significance of the regression coefficients from a value of 0, "...and a chi-square table that evaluates goodness-of-fit over the range of predictions" (Hamilton 1974). Of the three, Hamilton suggests use of the chi-square statistic for screening alternative models, but he also states that the final choice "... is left to the discretion of the user."

The dichotomous dependent variable is defined to be 1 if the tree has any cull in its total stem and 0 if not. The resulting equations for cubic foot volume, however, are to be applied to both total stem and merchantable cubic foot net volume estimation. It was felt that, in most cases, if the tree had cull in the total stem it would also have cull in the merchantable portion. In those cases where removal of the top also removed the cull portion, the fraction cull in the tree would then be 0, and this is a legitimate value in the final fraction cull model for merchantable cubic foot volume.

For each sp-NF combination, 10 models were fitted with d.b.h., total tree height, and number of tips as the tree attributes used for independent variables. Five models had one independent variable (H,D,T,DH, or D^2H) and the rest had two independent variables (H,D;H,T;D,T;DH,T; or D^2H,T). Generally, the final runs picked were the ones that minimized the chi-square statistic while maintaining the highest significance level attained by the F-statistic for the one- or two-independent variable models (that is, if some of the one- or two-variable models were significant at the 99 percent level, then the final model was picked from those that minimized the chi-square statistic). In some cases where the chi-square statistics were close, a model with a slightly higher chi-square statistic was picked if the F- and t-statistics were considerably larger.

One- and two-variable models are presented in those instances where the second variable improved the model. The added variable, number of tips in all cases, was not always statistically significant, but the resulting model behaved as expected (that is, as the number of tips increased, so did the probability of cull).

Some data sets were combined to gain data strength. Before combining, however, the preliminary models and mean values of PrC_c were examined to assure compatibility. Engelmann spruce and corkbark fir were separated because it was found that their cull structures were very different.

Damage information was available on the data sets from the Santa Fe and Carson National Forests. Therefore, in those cases where enough common damage was present to justify the effort, the previously picked models were fitted with dichotomous damage variables added. These damage variables did not prove to be significant.

All final equations were plotted and checked for reasonableness.

XI. Fraction Cull in Total Stem Cubic Foot Volume Given the Tree Is Unsound--Unforked and Forked Trees

Like the probability of a tree being unsound, fraction cull takes on a value that ranges from 0 to 1. To provide some control over the value of fraction cull, the following model was used:

$$FC_t = h_t(1.0 - e^{Y_t}) \qquad (27)$$

where

FC_t = Predicted fraction cull in total stem cubic foot volume given the tree is unsound

Y_t = A function of the tree's attributes

h_t = A final constant value.

th this model, fraction cull will have an asymptotic maximum value of h_t and, there-
re, h_t should be less than or equal to 1. Unfortunately, this model does not prevent
action cull from becoming less than 0.

The following process was used to determine the appropriate sp-NF parameters for
del (27). First, the model:

$$\ln(1.0 - \frac{FC}{h}) = Y$$

ere

FC = Actual fraction cull in total stem cubic foot volume given the tree is unsound

Y = A function of the tree's attributes

h = An intermediate constant value

s screened through linear regression using various functions of d.b.h., total tree
ight, number of tips, position to first fork, and damage information as independent
riables in Y, and also using various dependent variables formed by varying the value
h from the maximum FC in the data set to a value of 1. For each combination group
th a specified number of independent variables from the screening run, that combina-
on of Y and h which minimized RMSQR was picked, along with several other combinations,
at were almost as good. These models were next fitted, transformed back into model
7), and then tabulated and checked for reasonableness. The model with the lowest
SQR that gave reasonable results was then fitted with least squares regression through
e origin for a slope correction to adjust the model for possible log bias. This slope
rrection was then incorporated into the initial value of h to give the final value of
in model (27). Y_t is the final function of Y. As a final check, the models were
ain tabulated.

On the Douglas-fir data set, the final model proved to be worse than a mean value
FC_t. Therefore, the following model was fitted:

$$FC_t = b_0 - b_1 e^{Y_t}. \qquad (29)$$

e resulting model was better than the mean, and tabulation revealed that it behaved
rrectly. Model (29) was easily transformed back to model (27) by setting b_0 equal to
and adding $\ln(b_1/b_0)$ to Y_t.

Again, data sets were combined based on the results of the screening runs and upon
e mean FC_t values of the data sets to be combined.

Fraction Cull in Merchantable Cubic Foot Volume of Unsound Trees

For each sp-NF combination, the same independent variables used in the total stem
bic foot fraction cull models were fitted to each top diameter data set with a vari-
le h in model (28). An examination of the various runs across top diameter was made
l a value of h was picked that did the best overall job of minimizing the RMSQR
lues.

Using the value of h, the resulting regression coefficients of Y were modeled as functions of top diameter to obtain the final equations of Y_m in the model:

$$FC_m = h(1.0 - e^{Y_m}) \quad (30)$$

where

FC_m = Predicted fraction cull in merchantable cubic foot volume given the tree is unsound

Y_m = A function of the tree's attributes and top diameter

h = An intermediate constant value.

Model (30) was then fitted to the data set incorporating all top diameters with least squares regression to obtain a slope correction to adjust the model for possible log bias, and this slope correction was incorporated with h to give the final value, h_m, in the standard form:

$$FC_m = h_m(1.0 - e^{Y_m}) \quad (31)$$

where

h_m = A final constant value.

The final models were tabulated and checked for reasonableness. This procedure proved to work well on all data sets except Engelmann spruce and Douglas-fir. On these two data sets, a model of the form:

$$FC_m = b_0 - b_1 e^{Y_m} \quad (32)$$

was fitted. Tabulation of these runs indicated that they performed well. They were then converted to the standard form of model (32) using the fact that b_0 equals h_m and by adding $\ln(b_1/b_0)$ to Y_m.

Because of the high values of RMSQR, it was decided to provide an optional model to predict mean FC_m as a function of top diameter. Plots of the means over top diameter indicated that power functions of top diameter would be appropriate. The means were then weighted by their number of observations and screened with numerous power transforms on top diameter. The maximum number of independent variables in the screening run was limited to the value of 1 plus the number of maxima or minima the plots had shown. A final model was selected based on its behavior and the magnitude of its RMSQ.

XIII. Probability of Tree Being Unsound in Board Foot Volume--Unforked and Forked Trees

An examination of the data indicated that International 1/4-inch and Scribner board foot volumes were always sound or unsound together. Therefore, one model was developed that is applicable to both.

The techniques used were basically the same as those used for cubic foot volume. The damage information did prove, however, to be statistically significant at the 95 percent level on the blackjack pine and Douglas-fir data sets. The model with damage for white fir was almost significant and, because it behaved reasonably, it was also included.

Again, all curves were plotted as a final check.

V. Fraction Cull in International 1/4-inch Board Foot Volume Given the Tree Is Unsound--Unforked and Forked Trees

For fraction cull in International 1/4-inch board foot volume, the following model s used:

$$FC_I = h_I e^{Y_I} \quad (33)$$

ere

FC_I = Predicted fraction cull in International 1/4-inch board foot volume given the tree is unsound

Y_I = A function of the tree's attributes

h_I = A constant.

is model differs from models (27) and (32) because (33) is asymptotic to 0 instead of and, therefore, it will allow predicted values of FC_I to exceed 1, which is just the posite from models (27) and (32). This change in model form was by oversight rather an design, even though it does not affect the legitimacy of the results.

To fit model (33), the following model was first fitted and screened using the same sic procedures as in the cubic foot fraction cull equations:

$$\ln(FC) = Y \quad (34)$$

ere

FC = Actual fraction cull in International 1/4-inch board foot volume given the tree is unsound

Y = A function of the tree's attributes.

is model was then transformed back to the form of model (33) and h_I was found by least uares regression through the origin to correct the model for possible log bias. The dels were tabulated and those that were reasonable and minimized RMSQR were picked. l reasonable models examined for Engelmann spruce and for corkbark fir proved to be ch worse than the mean and, therefore, the models were dropped.

To gain data strength, yellow pine and Douglas-fir were combined across all tional Forests (but not with each other).

Fraction Cull in Scribner Board Foot Volume Given The Tree Is Unsound--Unforked and Forked Trees

The procedure and model forms used for fraction cull in Scribner board foot volume re virtually the same as those used for fraction cull in International 1/4-inch board ot volume.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

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Comprehensive tree volume equations and the methods used to derive them are presented for the major tree species of New Mexico and Arizona. Selected tree volume tables for unforked trees can be found in the companion publication, "Comprehensive tree volume equations for major species of New Mexico and Arizona: II. Tables for unforked trees."

KEYWORDS: volume equations, major tree species, New Mexico, Arizona, gross volume, net volume, unforked tree, forked tree, total stem cubic foot volume, merchantable cubic foot volume, Scribner board foot volume, International 1/4-inch board foot volume.

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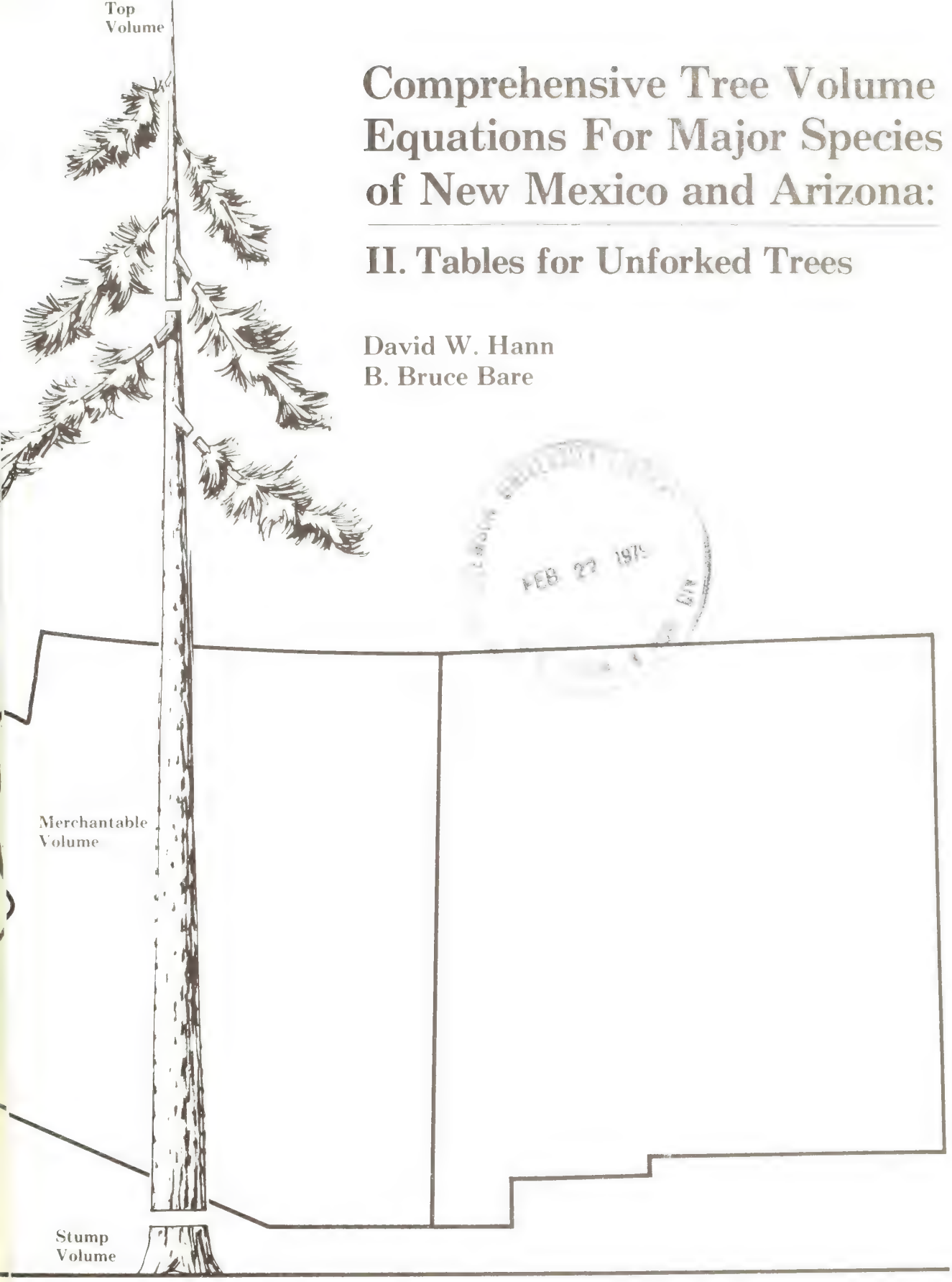

Comprehensive Tree Volume Equations For Major Species of New Mexico and Arizona:

II. Tables for Unforked Trees

David W. Hann
B. Bruce Bare

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COMPREHENSIVE TREE VOLUME EQUATIONS FOR MAJOR SPECIES OF NEW MEXICO AND ARIZONA:

II. TABLES FOR UNFORKED TREES

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RESEARCH SUMMARY

Selected volume tables for unforked trees are presented for major species of New Mexico and Arizona. The volume equations used to derive these tables are described in the companion publication, "Comprehensive tree volume equations for major species of New Mexico and Arizona: I. Results and Methodology."

INTRODUCTION

The tree volume tables presented here were computed from volume equations developed r the major tree species on five National Forests in New Mexico and Arizona (table A). e equations and the methodology used to derive them can be found in the companion blication, "Comprehensive tree volume equations for major species of New Mexico and izona: I. Results and methodology."

For each species and National Forest combination, tables for the following un- rked tree volumes are given:

1. Total stem gross cubic foot volume
2. Total stem net cubic foot volume
3. Gross merchantable cubic foot volume to a top diameter inside bark (d.i.b.) of 4 inches
4. Net merchantable cubic foot volume to a top d.i.b. of 4 inches
5. Gross merchantable cubic foot volume to a top d.i.b. of 6 inches
6. Net merchantable cubic foot volume to a top d.i.b. of 6 inches
7. Gross International 1/4-inch board foot volume to a top d.i.b. of 6 inches
8. Net International 1/4-inch board foot volume to a top d.i.b. of 6 inches
9. Gross Scribner board foot volume to a top d.i.b. of 6 inches
10. Net Scribner board foot volume to a top d.i.b. of 6 inches.

The two variables necessary to use these tables are diameter at breast height .b.h.) and total tree height. Also presented in the tables are the number of trees, diameter class and by height class, that were used in the development of the equa- ons. It should be noted that, with the exception of total stem cubic foot volume bles, tree counts across diameter classes will not necessarily add to the tree counts ross height classes. This apparent discrepancy arises because the tables begin with at diameter class that is one class larger than the merchantable top diameter. Be- use some of the trees used in developing the equations had a diameter smaller than is diameter class, they were eliminated from the tree counts.

Table A.--*Data sources*

Species	National Forest				
	Coconino	Tonto	Lincoln	Santa Fe	Carson
Blackjack pine[1] (*Pinus ponderosa* Laws.)	X	X	X	X	X
Yellow pine[1] (*Pinus ponderosa* Laws.)	X	X	X	X	X
Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Mirb.] Franco)		X	X	X	X
White fir (*Abies concolor* [Gord. and Glend.])			X	X	X
Southwestern white pine (*Pinus flexilis* var. *reflexa* Engelm.)			X	X	X
Engelmann spruce (*Picea engelmannii* Parry)			X	X	X
Aspen (*Populus tremuloides* Michx.)				X	X
Corkbark fir (*Abies lasiocarpa* var. *arizonica* [Merriam] Lemm.)				X	X

[1]In the Southwest, blackjack and yellow pines are distinguished by their bark colors; blackjack pines have very dark bark and yellow pines heavily plated, orange bark. This distinction is based on age, growth, and vigor differences rather than botanical differences, but foresters have found it useful in forest management planning.

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INDEX TO THE VOLUME TABLES

I. Southwestern white pine on the Santa Fe, Carson, and Lincoln National Forests

A. Cubic Foot Volume

1. Total stem gross.....
2. Total stem net..... 9
3. Gross merchantable to top d.i.b. of 4 inches..... 10
4. Net merchantable to top d.i.b. of 4 inches..... 11
5. Gross merchantable to top d.i.b. of 6 inches..... 12
6. Net merchantable to top d.i.b. of 6 inches..... 13

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches..... 14
2. Net International 1/4-inch to top d.i.b. of 6 inches..... 15
3. Gross Scribner to top d.i.b. of 6 inches..... 16
4. Net Scribner to top d.i.b. of 6 inches..... 17

II. Engelmann spruce and corkbark fir on the Santa Fe, Carson, and Lincoln National Forests

A. Cubic Foot Volume

1. Total stem gross..... 18
2. Total stem net--Engelmann spruce..... 19
3. Total stem net--corkbark fir..... 20
4. Gross merchantable to top d.i.b. of 4 inches..... 21
5. Net merchantable to top d.i.b. of 4 inches--Engelmann spruce. 22
6. Net merchantable to top d.i.b. of 4 inches--corkbark fir..... 23
7. Gross merchantable to top d.i.b. of 6 inches..... 24
8. Net merchantable to top d.i.b. of 6 inches--Engelmann spruce. 25
9. Net merchantable to top d.i.b. of 6 inches--corkbark fir..... 26

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches..... 27
2. Net International 1/4-inch to top d.i.b. of 6 inches--Engelmann spruce..... 28
3. Net International 1/4-inch to top d.i.b. of 6 inches--corkbark fir..... 29
4. Gross Scribner to top d.i.b. of 6 inches..... 30
5. Net Scribner to top d.i.b. of 6 inches--Engelmann spruce..... 31
6. Net Scribner to top d.i.b. of 6 inches--corkbark fir..... 32

Page

III. Yellow pine on the Santa Fe, Carson, Lincoln, Coconino, and Tonto National Forests

A. Cubic Foot Volume

1. Total stem gross..... 33
2. Total stem net--Santa Fe and Carson National Forests..... 34
3. Total stem net--Lincoln, Coconino, and Tonto National Forests. 35
4. Gross merchantable to top d.i.b. of 4 inches..... 36
5. Net merchantable to top d.i.b. of 4 inches--Santa Fe and Carson National Forests..... 37
6. Net merchantable to top d.i.b. of 4 inches--Lincoln, Coconino, and Tonto National Forests..... 38
7. Gross merchantable to top d.i.b. of 6 inches..... 39
8. Net merchantable to top d.i.b. of 6 inches--Santa Fe and Carson National Forests 40
9. Net merchantable to top d.i.b. of 6 inches--Lincoln, Coconino, and Tonto National Forests 41

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches..... 42
2. Net International 1/4-inch to top d.i.b. of 6 inches--Santa Fe and Carson National Forests..... 43
3. Net International 1/4-inch to top d.i.b. of 6 inches--Lincoln, Coconino, and Tonto National Forests..... 44
4. Gross Scribner to top d.i.b. of 6 inches..... 45
5. Net Scribner to top d.i.b. of 6 inches--Santa Fe and Carson National Forests..... 46
6. Net Scribner to top d.i.b. of 6 inches--Lincoln, Coconino, and Tonto National Forests..... 47

IV. Blackjack pine on the Lincoln, Coconino, and Tonto National Forests

A. Cubic Foot Volume

1. Total stem gross..... 48
2. Total stem net--Lincoln National Forest..... 49
3. Total stem net--Coconino National Forest..... 50
4. Total stem net--Tonto National Forest..... 51
5. Gross merchantable to top d.i.b. of 4 inches..... 52
6. Net merchantable to top d.i.b. of 4 inches--Lincoln National Forest..... 53
7. Net merchantable to top d.i.b. of 4 inches--Coconino National Forest..... 54
8. Net merchantable to top d.i.b. of 4 inches--Tonto National Forest..... 55
9. Gross merchantable to top d.i.b. of 6 inches..... 56
10. Net merchantable to top d.i.b. of 6 inches--Lincoln National Forest..... 57
11. Net merchantable to top d.i.b. of 6 inches--Coconino National Forest..... 58
12. Net merchantable to top d.i.b. of 6 inches--Tonto National Forest..... 59

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches.... 60
2. Net International 1/4-inch to top d.i.b. of 6 inches--Lincoln National Forest.... 61
3. Net International 1/4-inch to top d.i.b. of 6 inches--Coconino National Forest.... 62
4. Net International 1/4-inch to top d.i.b. of 6 inches--Tonto National Forest.... 63
5. Gross Scribner to top d.i.b. of 6 inches.... 64
6. Net Scribner to top d.i.b. of 6 inches--Lincoln National Forest.... 65
7. Net Scribner to top d.i.b. of 6 inches--Coconino National Forest.... 66
8. Net Scribner to top d.i.b. of 6 inches--Tonto National Forest.... 67

V. Blackjack pine on the Santa Fe and Carson National Forests

A. Cubic Foot Volume

1. Total stem gross.... 68
2. Total stem net.... 69
3. Gross merchantable to top d.i.b. of 6 inches.... 70
4. Net merchantable to top d.i.b. of 6 inches.... 71
5. Gross merchantable to top d.i.b. of 6 inches.... 72
6. Net merchantable to top d.i.b. of 6 inches.... 73

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches.... 74
2. Net International 1/4-inch to top d.i.b. of 6 inches.... 75
3. Gross Scribner to top d.i.b. of 6 inches.... 76
4. Net Scribner to top d.i.b. of 6 inches.... 77

VI. Douglas-fir on the Lincoln and Tonto National Forests

A. Cubic Foot Volume

1. Total stem gross.... 78
2. Total stem net.... 79
3. Gross merchantable to top d.i.b. of 4 inches.... 80
4. Net merchantable to top d.i.b. of 4 inches.... 81
5. Gross merchantable to top d.i.b. of 6 inches.... 82
6. Net merchantable to top d.i.b. of 6 inches.... 83

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches.... 84
2. Net International 1/4-inch to top d.i.b. of 6 inches.... 85
3. Gross Scribner to top d.i.b. of 6 inches.... 86
4. Net Scribner to top d.i.b. of 6 inches.... 87

Page

VII. Douglas-fir on the Santa Fe and Carson National Forests

A. Cubic Foot Volume

1. Total stem gross..... 88
2. Total stem net..... 89
3. Gross merchantable to top d.i.b. of 4 inches..... 90
4. Net merchantable to top d.i.b. of 4 inches..... 91
5. Gross merchantable to top d.i.b. of 6 inches..... 92
6. Net merchantable to top d.i.b. of 6 inches..... 93

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches..... 94
2. Net International 1/4-inch to top d.i.b. of 6 inches..... 95
3. Gross Scribner to top d.i.b. of 6 inches..... 96
4. Net Scribner to top d.i.b. of 6 inches..... 97

VIII. Aspen on the Santa Fe and Carson National Forests

A. Cubic Foot Volume

1. Total stem gross..... 98
2. Total stem net..... 99
3. Gross merchantable to top d.i.b. of 4 inches..... 100
4. Net merchantable to top d.i.b. of 4 inches..... 101
5. Gross merchantable to top d.i.b. of 6 inches..... 102
6. Net merchantable to top d.i.b. of 6 inches..... 103

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches..... 104
2. Net International 1/4-inch to top d.i.b. of 6 inches..... 105
3. Gross Scribner to top d.i.b. of 6 inches..... 106
4. Net Scribner to top d.i.b. of 6 inches..... 107

IX. White fir on the Lincoln National Forest

A. Cubic Foot Volume

1. Total stem gross..... 108
2. Total stem net..... 109
3. Gross merchantable to top d.i.b. of 4 inches..... 110
4. Net merchantable to top d.i.b. of 4 inches..... 111
5. Gross merchantable to top d.i.b. of 6 inches..... 112
6. Net merchantable to top d.i.b. of 6 inches..... 113

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches..... 114
2. Net International 1/4-inch to top d.i.b. of 6 inches..... 115
3. Gross Scribner to top d.i.b. of 6 inches..... 116
4. Net Scribner to top d.i.b. of 6 inches..... 117

X. White fir on the Santa Fe and Carson National Forest

A. Cubic Foot Volume

1. Total stem gross..... 118
2. Total stem net..... 119
3. Gross merchantable to top d.i.b. of 4 inches..... 120
4. Net merchantable to top d.i.b. of 4 inches..... 121
5. Gross merchantable to top d.i.b. of 6 inches..... 122
6. Net merchantable to top d.i.b. of 6 inches..... 123

B. Board Foot Volume

1. Gross International 1/4-inch to top d.i.b. of 6 inches..... 124
2. Net International 1/4-inch to top d.i.b. of 6 inches..... 125
3. Gross Scribner to top d.i.b. of 6 inches..... 126
4. Net Scribner to top d.i.b. of 6 inches..... 127

TOTAL STEM GROSS CUBIC FOOT VOLUME-UNGROWED TREES
SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
1	.2															
2	.2	.3														
3	.3	.5	.7													
4	.5	.8	1.1	1.5												
5	.7	1.2	1.7	2.2	2.7											
6	.9	1.6	2.4	3.1	3.8	4.6										
7	1.2	2.2	3.1	4.1	5.1	6.1	7.1									
8	1.5	2.8	4.1	5.4	6.7	8.0	9.3	10.6								
9	1.8	3.5	5.1	6.7	8.4	10.0	11.7	13.3	15.0							
10		4.2	6.3	8.3	10.3	12.4	14.4	16.4	18.5							
11		5.1	7.5	10.0	12.5	14.9	17.4	19.8	22.3	24.8						
12		6.0	8.9	11.9	14.8	17.7	20.6	23.6	26.5	29.4						
13		7.0	10.5	13.9	17.3	20.8	24.2	27.6	31.1	34.5	37.9					
14		8.1	12.1	16.1	20.1	24.1	28.0	32.0	36.0	40.0	44.0					
15			13.9	18.5	23.0	27.6	32.2	36.7	41.3	45.9	50.5	55.0				
16			15.8	21.0	26.2	31.4	36.6	41.8	47.0	52.2	57.4	62.6				
17			17.8	23.7	29.5	35.4	41.3	47.2	53.0	58.9	64.8	70.6	76.5			
18			19.9	26.5	33.1	39.7	46.3	52.8	59.4	66.0	72.6	79.2	85.8			
19			22.2	29.5	36.8	44.2	51.5	58.9	66.2	73.5	80.9	88.2	95.5	102.9		
20				32.7	40.8	48.9	57.1	65.2	73.3	81.5	89.6	97.7	105.9	114.0		
21				36.0	45.0	53.9	62.9	71.9	80.8	89.8	98.8	107.7	116.7	125.6	134.6	
22				39.5	49.3	59.2	69.0	78.9	88.7	98.5	108.4	118.2	128.0	137.9	147.7	
23				43.2	53.9	64.7	75.4	86.2	96.9	107.7	118.4	129.2	139.9	150.7	161.4	
24				47.0	58.7	70.4	82.1	93.8	105.5	117.2	128.9	140.6	152.4	164.1	175.8	
25					63.7	76.4	89.1	101.8	114.5	127.2	139.9	152.6	165.3	178.0	190.7	
26					68.9	82.6	96.3	110.1	123.8	137.6	151.3	165.0	178.8	192.5	206.3	
27					74.2	89.1	103.9	118.7	133.5	148.3	163.1	178.0	192.8	207.6	222.4	
28					79.8	95.8	111.7	127.6	143.6	159.5	175.4	191.4	207.3	223.2	239.2	
29					85.6	102.7	119.8	136.9	154.0	171.1	188.2	205.3	222.4	239.5	256.6	
30						109.9	128.2	146.5	164.8	183.1	201.4	219.7	238.0	256.3	274.5	
31						117.4	136.9	156.4	176.0	195.5	215.0	234.5	254.1	273.6	293.1	
32						125.0	145.9	166.7	187.5	208.3	229.1	249.9	270.7	291.5	312.4	
33						133.0	155.1	177.2	199.4	221.5	243.6	265.8	287.9	310.0	332.2	
34						141.1	164.6	188.1	211.6	235.1	258.6	282.1	305.6	329.1	352.6	
35							174.4	199.3	224.2	249.1	274.0	298.9	323.8	348.7	373.6	
36							184.5	210.9	237.2	263.6	289.9	316.3	342.6	368.9	395.3	
37							194.9	222.8	250.6	278.4	306.2	334.1	361.9	389.7	417.5	
38							205.6	235.0	264.3	293.7	323.0	352.4	381.7	411.1	440.4	
39							216.6	247.5	278.4	309.3	340.2	371.1	402.0	433.0	463.9	
40								260.3	292.8	325.4	357.9	390.4	422.9	455.4	488.0	
41								273.5	307.7	341.8	376.0	410.2	444.3	478.5	512.7	
42								287.0	322.8	358.7	394.5	430.4	466.3	502.1	538.0	
43								300.8	338.4	376.0	413.6	451.1	488.7	526.3	563.9	
44								315.0	354.3	393.7	433.0	472.4	511.7	551.0	590.4	
45									370.6	411.7	452.9	494.1	535.2	576.4	617.5	
46									387.2	430.2	473.2	516.3	559.3	602.3	645.3	
47									404.2	449.1	494.0	538.9	583.8	628.7	673.6	
48									421.6	468.4	515.3	562.1	608.9	655.8	702.6	
									439.4	488.2	537.0	585.8	634.6	683.4	732.2	

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	RADIO TOTAL
1	.2															
2	.2	.3														
3	.3	.5	.7													
4	.5	.8	1.1	1.5												
5	.7	1.2	1.7	2.2	2.7											
6	.9	1.6	2.3	3.1	3.8	4.5										
7	1.2	2.1	3.1	4.1	5.1	6.1	7.0									
8	1.5	2.8	4.0	5.3	6.6	7.8	9.1	10.3								
9	1.8	3.4	5.1	6.7	8.3	9.9	11.4	12.9	14.5							
10		4.2	6.2	8.2	10.1	12.0	13.9	15.8	17.7							
11		5.0	7.4	9.8	12.1	14.4	16.7	19.0	21.3	23.6						
12		6.0	8.8	11.6	14.4	17.0	19.7	22.4	25.1	27.8						
13		7.0	10.3	13.6	16.7	19.8	22.9	26.0	29.1	32.2	35.4					
14		8.0	11.9	15.6	19.3	22.8	26.3	29.8	33.4	37.0	40.6					
15			13.6	17.9	22.1	26.0	29.6	33.3	37.1	41.0	45.0					
16			15.4	20.2	24.8	29.2	33.7	38.1	42.6	47.1	51.7					
17			17.3	22.7	27.4	32.8	37.7	42.6	47.6	52.6	57.6					
18			19.3	25.3	31.1	36.5	41.8	47.2	52.6	58.2	63.7					
19			21.5	28.1	34.9	40.3	46.1	51.9	57.8	63.8	69.8					
20				31.0	37.7	44.2	50.6	56.6	63.1	69.6	76.2					
21				33.9	41.2	48.2	55.2	61.8	68.7	75.8	82.9					
22				37.0	45.0	52.4	59.6	66.9	74.	81.8	89.4					
23				40.2	48.8	56.7	64.4	72.1	80.0	87.9	96.0					
24				43.5	52.7	61.2	69.3	77.4	85.7	94.1	102.6					
25					56.7	65.7	74.2	82.8	91.7	100.7	109.8					
26					60.	70.2	79.3	88.4	97.8	107.3	117.0					
27					65.3	75.	84.6	94.2	104.0	114.1	124.3					
28					69.9	79.9	89.9	99.9	110.3	120.9	131.7					
29					74.7	84.7	94.9	105.3	115.9	126.7	137.7					
30						89.7	100.2	111.0	121.8	132.8	144.0					
31						94.8	105.6	116.5	127.6	138.9	150.4					
32						100.0	111.2	122.2	133.6	145.2	156.9					
33						105.2	116.9	128.1	139.6	151.5	163.5					
34						110.6	122.8	134.2	145.8	157.8	170.2					
35						116.1	128.8	140.5	152.3	164.3	176.4					
36						121.7	134.9	147.1	159.3	171.0	182.8					
37						127.4	141.1	153.9	166.5	178.1	189.8					
38						133.2	147.5	160.8	174.0	185.4	196.9					
39						139.2	153.9	167.8	181.7	193.0	204.3					
40						145.3	160.5	174.9	189.5	200.8	211.9					
41						151.5	167.2	182.2	197.3	208.8	219.7					
42						157.8	174.0	189.6	205.3	216.9	227.7					
43						164.2	180.9	197.1	213.4	225.2	235.9					
44						170.7	187.9	204.7	221.6	233.6	244.3					
45						177.3	195.0	212.4	229.9	242.1	252.9					
46						184.0	202.2	220.2	238.3	250.7	261.6					
47						190.8	209.6	228.1	246.8	259.4	270.4					
48						197.7	217.1	236.1	255.4	268.2	279.3					
49						204.7	224.7	244.2	264.1	277.1	288.3					
50						211.8	232.4	252.4	272.9	286.1	297.4					

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES FOR WESTERN TREES
SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

| DBH CLASS | HEIGHT CLASS 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |

SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS															BASI AREA
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
5	.4	.7	.9	1.1	1.4											
6	.7	1.2	1.7	2.0	2.7	3.2										
7	.9	1.7	2.5	3.4	4.2	5.0	5.2									
8	1.1	2.3	3.5	4.6	5.7	6.6	8.0	9.1								
9	1.4	2.9	4.4	5.9	7.4	8.9	10.3	11.6	12.2							
10		3.6	5.5	7.4	9.3	11.1	12.9	14.7	16.4							
11		4.4	6.7	9.0	11.2	13.5	15.7	17.4	20.1	20.3						
12		5.2	8.0	10.7	13.4	16.0	18.8	21.3	24.2	24.4						
13		6.0	9.3	12.4	15.7	18.8	21.8	24.9	27.9	31.0	34.1					
14		7.0	10.6	14.2	17.1	21.7	25.2	28.7	32.2	34.8	34.8					
15			12.3	16.6	20.7	24.7	28.7	32.7	36.7	40.7	44.7	45.4				
16			14.1	18.7	23.4	28.0	32.4	36.9	41.4	45.8	50.3	50.1				
17			16.7	21.1	26.2	31.3	36.4	41.2	46.2	51.3	56.4	61.7	61.7			
18			17.6	23.8	29.3	34.9	40.3	45.7	51.3	56.7	62.2	67.8	73.4			
19			19.3	24.1	32.5	38.6	44.5	50.5	56.5	62.5	68.5	75.1	81.4	87.7		
20				28.6	35.6	42.4	48.8	55.3	61.8	68.5	75.4	82.1	88.9	95.6		
21				31.4	38.8	46.3	53.3	60.3	67.4	74.6	81.9	89.4	96.7	104.1	111.4	
22				34.1	42.3	50.4	57.9	65.4	73.0	80.7	88.7	96.7	104.7	112.8	120.8	
23				37.4	46.4	55.2	63.4	71.6	79.9	88.1	96.5	104.9	113.4	121.9	130.4	
24				40.1	49.9	59.4	67.9	76.6	85.4	94.2	103.2	112.2	121.2	130.3	139.4	
25				43.1	53.5	63.6	72.4	81.3	90.3	99.5	108.8	118.2	127.7	137.3	146.9	
26				46.1	57.0	67.7	77.0	86.1	95.3	104.8	114.4	124.1	133.9	143.8	153.8	
27					60.4	71.8	81.4	90.9	100.4	110.1	120.0	130.0	140.1	150.3	160.6	
28					63.9	75.9	85.8	95.7	105.6	115.5	125.6	135.8	146.1	156.5	167.0	
29					67.4	80.0	90.2	100.4	110.8	121.1	131.3	141.6	152.1	162.7	173.4	
30					70.9	84.1	94.7	105.2	115.9	126.6	137.3	148.1	159.0	169.9	180.9	
31					74.4	88.2	99.2	110.0	121.0	132.0	143.1	154.3	165.5	176.8	188.2	
32					77.9	92.3	103.7	114.9	126.1	137.4	148.8	160.3	171.8	183.4	195.1	
33					81.4	96.4	108.2	119.8	131.4	142.9	154.5	166.2	178.0	189.8	201.7	
34					84.9	100.5	112.7	124.8	136.7	148.5	160.3	172.2	184.2	196.2	208.3	
35					88.4	104.6	117.2	129.7	142.1	154.1	166.1	178.2	190.4	202.6	214.9	
36					91.9	108.7	121.7	134.7	147.4	159.8	172.0	184.2	196.5	208.9	221.4	
37					95.4	112.8	126.2	139.6	152.8	165.4	177.9	190.3	202.7	215.3	227.9	
38					98.9	116.9	130.7	144.6	158.1	171.1	183.8	196.3	208.8	221.6	234.4	
39					102.4	121.0	135.2	149.5	163.5	176.7	189.7	202.4	214.9	227.9	240.9	
40					105.9	125.1	139.7	154.5	168.8	182.4	195.7	208.4	221.0	234.2	247.4	
41					109.4	129.2	144.2	159.4	174.2	188.0	201.6	214.5	227.1	240.5	253.9	
42					112.9	133.3	148.7	164.4	179.5	193.7	207.6	220.6	233.2	246.8	260.4	
43					116.4	137.4	153.2	169.3	184.9	199.3	213.5	226.7	239.3	253.1	266.9	
44					119.9	141.5	157.7	174.3	190.2	204.9	219.5	232.8	245.4	259.4	273.4	
45					123.4	145.6	162.2	179.2	195.6	210.5	225.4	238.9	251.5	265.7	279.9	
46					126.9	149.7	166.7	184.2	200.9	216.1	231.4	245.0	257.6	272.0	286.4	
47					130.4	153.8	171.2	189.1	206.3	221.7	237.3	251.1	263.7	278.3	292.9	
48					133.9	157.9	175.7	194.0	211.6	227.3	243.3	257.2	269.8	284.6	299.4	
49					137.4	162.0	180.2	198.9	216.9	232.9	249.2	263.3	275.9	290.9	305.9	
50					140.9	166.1	184.7	203.8	222.2	238.5	255.2	269.4	282.0	297.2	312.4	
51					144.4	170.2	189.2	208.7	227.5	244.1	261.1	275.5	288.1	303.5	318.9	
52					147.9	174.3	193.7	213.6	232.8	249.7	267.1	281.6	294.2	309.8	325.4	
53					151.4	178.4	198.2	218.5	238.1	255.3	273.0	287.7	300.3	316.1	331.9	
54					154.9	182.5	202.7	223.4	243.4	260.9	278.9	293.8	306.4	322.4	338.4	
55					158.4	186.6	207.2	228.3	248.7	266.5	284.8	299.9	312.5	328.7	344.9	
56					161.9	190.7	211.7	233.2	254.0	272.1	290.7	306.0	318.6	335.0	351.4	
57					165.4	194.8	216.2	238.1	259.3	277.7	296.6	312.1	324.7	341.3	357.9	
58					168.9	198.9	220.7	243.0	264.6	283.3	302.5	318.2	330.8	347.6	364.4	
59					172.4	203.0	225.2	247.9	269.9	288.9	308.4	324.3	336.9	353.9	370.9	
60					175.9	207.1	229.7	252.8	275.2	294.5	314.3	330.4	343.0	360.2	377.4	
61					179.4	211.2	234.2	257.7	280.5	300.1	320.2	336.5	349.1	366.5	383.9	
62					182.9	215.3	238.7	262.6	285.8	305.7	326.1	342.6	355.2	372.8	390.4	
63					186.4	219.4	243.2	267.5	291.1	311.3	332.0	348.7	361.3	379.1	396.9	
64					189.9	223.5	247.7	272.4	296.4	316.9	337.9	354.8	367.4	385.4	403.4	
65					193.4	227.6	252.2	277.3	301.7	322.5	343.8	360.9	373.5	391.7	409.9	
66					196.9	231.7	256.7	282.2	307.0	328.1	349.7	367.0	379.6	398.0	416.4	
67					200.4	235.8	261.2	287.1	312.3	333.7	355.6	373.1	385.7	404.3	422.9	
68					203.9	239.9	265.7	292.0	317.6	339.3	361.5	379.2	391.8	410.6	429.4	
69					207.4	244.0	270.2	296.9	322.9	344.9	367.4	385.3	397.9	416.9	435.9	
70					210.9	248.1	274.7	301.8	328.2	350.5	373.3	391.4	404.0	423.2	442.4	
71					214.4	252.2	279.2	306.7	333.5	356.1	379.2	397.5	410.1	429.5	448.9	
72					217.9	256.3	283.7	311.6	338.8	361.7	385.1	403.6	416.2	435.8	455.4	
73					221.4	260.4	288.2	316.5	344.1	367.3	391.0	409.7	422.3	442.1	461.9	
74					224.9	264.5	292.7	321.4	349.4	372.9	396.9	415.8	428.4	448.4	468.4	
75					228.4	268.6	297.2	326.3	354.7	378.5	402.8	421.9	434.5	454.7	474.9	
76					231.9	272.7	301.7	331.2	360.0	384.1	408.7	428.0	440.6	460.9	481.4	
77					235.4	276.8	306.2	336.1	365.3	389.7	414.6	434.1	446.7	467.2	487.9	
78					238.9	280.9	310.7	341.0	370.6	395.3	420.5	440.2	452.8	473.4	494.4	
79					242.4	285.0	315.2	345.9	375.9	400.9	426.4	446.3	458.9	479.6	500.4	
80					245.9	289.1	319.7	350.8	381.2	406.5	432.3	452.4	465.0	485.8	506.4	
81					249.4	293.2	324.2	355.7	386.5	412.1	438.2	458.5	471.1	491.8	512.4	
82					252.9	297.3	328.7	360.6	391.8	417.7	444.1	464.6	477.2	497.8	518.4	
83					256.4	301.4	333.2	365.5	397.1	423.3	450.0	470.7	483.3	503.8	524.4	
84					259.9	305.5	337.7	370.4	402.4	428.9	455.9	476.8	489.4	509.8	530.4	
85					263.4	309.6	342.2	375.3	407.7	434.5	461.8	482.9	495.5	515.8	536.4	
86					266.9	313.7	346.7	380.2	413.0	440.1	467.7	489.0	501.6	521.8	542.4	
87					270.4	317.8	351.2	385.1	418.3	445.7	473.6	495.1	507.7	527.8	548.4	
88					273.9	321.9	355.7	390.0	423.6	451.3	479.5	501.2	513.8	533.8	554.4	
89					277.4	326.0	360.2	394.9	428.9	456.9	485.4	507.3	519.9	539.8	560.4	
90					280.9	330.1	364.7	399.8	434.2	462.5	491.3	513.4	526.0	545.8	566.4	
91					284.4	334.2	369.2	404.7	439.5	468.1	497.2	519.5	532.1	551.8	572.4	
92					287.9	338.3	373.7	409.6	444.8	473.7	503.1	525.6	538.2	557.8	578.4	
93					291.4	342.4	378.2	414.5	450.1	479.3	509.0	531.7	544.3	563.8	584.4	
94					294.9	346.5	382.7	419.4	455.4	484.9	514.9	537.8	550.4	569.8	590.4	
95					298.4	350.6	387.2	424.3	460.7	490.5	520.8	543.9	556.5	575.8	596.4	
96					301.9	354.7	391.7	429.2	466.0	496.1	526.7	550.0	562.6	581.8	602.4	
97					305.4	358.8	396.2	434.1	471.3	501.7	532.6	556.1	568.7	587.8	608.4	
98					308.9	362.9	400.7	439.0	476.6	507.3	538.5	562.2	574.8	593.8	614.4	
99					312.4	367.0	405.2	443.9	481.9	512.9	544.4	568.3	580.9	599.8	620.4	
100					315.9	371.1	409.7	448.8	487.2	518.5	550.3	574.4	587.0	605.8	626.4	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES-UNFORKED TYPE
SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	AVG TRE
7	.5	.9	1.3	1.8	2.2	2.6	3.0									2
8	.8	1.6	2.5	3.3	4.1	5.0	5.8	6.6								1
9	1.1	2.4	3.6	4.9	6.1	7.4	8.7	9.9	11.2							2
10		3.2	4.9	6.6	8.3	9.9	11.6	13.3	15.0							2
11		4.0	6.1	8.3	10.5	12.7	14.8	17.0	19.2	21.3						2
12		4.8	7.5	10.2	12.9	15.5	18.2	20.9	23.5	26.2						2
13		5.8	9.0	12.2	15.4	18.6	21.8	25.0	28.2	31.4	34.6					3
14		6.7	10.5	14.3	18.1	21.9	25.7	29.4	33.2	37.0	40.8					3
15			12.2	16.6	21.0	25.4	29.7	34.1	38.5	42.9	47.3	51.7				4
16			13.9	19.0	24.0	29.0	34.1	39.1	44.2	49.2	54.2	59.3				5
17			15.8	21.5	27.2	33.0	38.7	44.4	50.1	55.8	61.6	67.3	73.0			1
18			17.7	24.2	30.6	37.1	43.5	50.0	56.4	62.9	69.3	75.8	82.2			1
19			19.8	27.0	34.2	41.4	48.7	55.9	63.1	70.3	77.5	84.7	91.9	99.1		1
20				30.0	38.0	46.0	54.0	62.0	70.1	78.1	86.1	94.1	102.1	110.1		2
21				33.1	42.0	50.8	59.7	68.5	77.4	86.2	95.1	103.9	112.8	121.6	130.5	1
22				36.4	46.1	55.8	65.6	75.3	85.1	94.8	104.5	114.3	124.0	133.7	143.5	1
23				39.8	50.4	61.1	71.8	82.4	93.1	103.7	114.4	125.0	135.7	146.3	157.0	2
24				43.4	55.0	66.6	78.2	89.8	101.4	113.1	124.7	136.3	147.9	159.5	171.1	0
25					59.7	72.3	84.9	97.5	110.2	122.8	135.4	148.0	160.6	173.2	185.9	0
26					64.6	78.2	91.9	105.6	119.2	132.9	146.5	160.2	173.9	187.5	201.2	1
27					69.7	84.4	99.1	113.9	128.6	143.4	158.1	172.9	187.6	202.3	217.1	1
28					74.9	90.8	106.7	122.5	138.4	154.3	170.1	186.0	201.8	217.7	233.6	1
29					80.4	97.4	114.5	131.5	148.5	165.5	182.6	199.6	216.6	233.6	250.7	0
30						104.3	122.5	140.7	159.0	177.2	195.4	213.7	231.9	250.1	268.3	0
31						111.4	130.8	150.3	169.9	189.3	208.7	228.2	247.7	267.1	286.6	1
32						118.7	139.4	160.2	181.0	201.7	222.5	243.2	264.0	284.7	305.5	0
33						126.2	148.3	170.4	192.5	214.6	236.6	258.7	280.8	302.9	324.9	1
34						134.0	157.5	180.9	204.3	227.8	251.2	274.7	298.1	321.6	345.0	1
35							166.9	191.7	216.6	241.4	266.3	291.1	316.0	340.8	365.7	0
36							176.6	202.9	229.1	255.4	281.7	308.0	334.3	360.6	386.9	0
37							186.5	214.3	242.1	269.9	297.6	325.4	353.2	381.0	408.7	0
38							196.8	226.1	255.4	284.7	314.0	343.3	372.6	401.9	431.2	0
39							207.3	238.1	269.0	299.9	330.7	361.6	392.5	423.3	454.2	1
40								250.5	283.0	315.5	347.9	380.4	412.9	445.4	477.8	0
41								263.2	297.3	331.4	365.6	399.7	433.8	467.9	502.1	0
42								276.2	312.0	347.8	383.6	419.5	455.3	491.1	526.9	0
43								289.5	327.1	364.6	402.1	439.7	477.2	514.8	552.3	0
44								303.1	342.5	381.8	421.1	460.4	499.7	539.0	578.3	0
45									358.2	399.3	440.5	481.6	522.7	563.8	604.9	0
46									374.3	417.3	460.3	503.2	546.2	589.2	632.2	0
47									390.8	435.6	480.5	525.4	570.2	615.1	660.0	0
48									407.6	454.4	501.2	548.0	594.8	641.6	688.4	0
49									424.7	473.5	522.3	571.1	619.8	668.6	717.4	0
50									442.3	493.0	543.8	594.6	645.4	696.2	747.0	0
BASIS TREES	0	1	2	7	9	4	6	5	3	1	1	0	0	0	0	

SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.5	.9	1.3	1.8	2.2	2.6	3.0									4
8	.8	1.6	2.5	3.3	4.1	4.9	5.7	6.5								5
9	1.1	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8							3
10		3.1	4.8	6.5	8.1	9.7	11.3	12.9	14.5							3
11		3.9	6.1	8.2	10.2	12.3	14.3	16.3	18.3	20.3						3
12		4.8	7.4	10.0	12.5	15.0	17.4	19.8	22.3	24.8						0
13		5.7	8.8	11.9	14.9	17.8	20.7	23.6	26.5	29.4	32.4					1
14		6.7	10.3	13.9	17.4	20.8	24.1	27.5	30.9	34.3	37.7					5
15			11.9	16.1	20.0	23.9	27.8	31.6	35.4	39.3	43.3	47.2				3
16			13.6	18.3	22.8	27.2	31.5	35.8	40.2	44.6	49.0	53.4				4
17			15.4	20.7	25.7	30.6	35.4	40.2	45.1	50.0	55.0	60.0	65.1			3
18			17.2	23.2	28.8	34.2	39.5	44.8	50.2	55.6	61.1	66.7	72.3			2
19			19.2	25.7	32.0	37.9	43.7	49.5	55.4	61.4	67.5	73.6	79.8	86.0		0
20				28.4	35.3	41.7	48.0	54.3	60.7	67.3	73.9	80.6	87.4	94.2		2
21				31.3	38.7	45.7	52.5	59.3	66.2	73.3	80.5	87.8	95.1	102.5	109.9	1
22				34.2	42.2	49.7	57.0	64.4	71.8	79.4	87.2	95.1	103.0	111.0	119.1	1
23				37.2	45.8	53.9	61.7	69.5	77.5	85.7	94.0	102.5	111.1	119.7	128.3	2
24				40.3	49.6	58.2	66.5	74.8	83.3	92.0	100.9	110.0	119.2	128.4	137.7	0
25					53.5	62.6	71.4	80.1	89.1	98.4	107.9	117.6	127.4	137.2	147.2	2
26					57.4	67.1	76.3	85.6	95.1	104.9	115.0	125.3	135.7	146.2	156.7	1
27					61.5	71.7	81.4	91.1	101.1	111.4	122.1	133.0	144.0	155.1	166.3	2
28					65.7	76.4	86.5	96.7	107.2	118.0	129.2	140.8	152.4	164.2	176.0	1
29					70.0	81.2	91.8	102.3	113.2	124.7	136.5	148.6	160.9	173.3	185.8	2
30						86.1	97.1	108.1	119.5	131.4	143.8	156.5	169.4	182.4	195.5	2
31						91.0	102.4	113.8	125.7	138.1	151.1	164.4	177.8	191.4	205.1	1
32						96.1	107.9	119.7	132.0	144.9	158.4	172.3	186.4	200.8	215.2	1
33						101.3	113.4	125.6	138.2	151.8	165.6	180.2	195.1	210.1	225.3	1
34						106.5	119.0	131.6	144.7	158.6	173.2	188.3	203.8	219.4	235.1	1
35							124.7	137.6	151.2	165.6	180.7	196.4	212.4	228.6	245.1	1
36							130.5	143.7	157.7	172.6	188.2	204.6	221.1	237.8	254.7	1
37							136.3	149.9	164.2	179.6	195.8	212.8	230.4	247.9	265.7	1
38							142.3	156.1	170.8	186.7	203.4	221.1	239.1	257.2	275.6	1
39							148.3	162.5	177.5	193.8	211.1	229.4	247.9	266.7	285.7	1
40								168.9	184.2	201.1	219.0	237.7	256.7	276.0	295.5	1
41								175.4	191.2	208.4	226.7	246.0	265.8	285.9	306.3	1
42								182.0	198.3	215.6	234.7	254.7	275.0	295.8	316.8	1
43								188.7	205.6	223.3	242.7	263.3	284.2	305.6	327.3	1
44								195.5	213.0	231.3	251.0	272.2	293.7	315.7	338.0	1
45									219.6	238.6	259.0	280.8	303.0	325.7	348.8	1
46									226.3	246.0	267.1	289.5	312.4	335.8	359.6	1
47									233.0	253.4	275.2	298.3	321.9	345.9	370.5	1
48									239.8	260.8	283.3	307.1	331.4	356.1	381.3	1
49									246.7	268.3	291.5	316.0	340.9	366.4	392.3	1
50									253.7	275.9	299.8	325.0	350.6	376.8	403.4	1
BASIC TREES	5	9	14	18	14	9	7	4	2	1	1	1	1	1	1	

GROSS INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB-UNFORKED TREES
SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	TALLY TREES
7	.6	1.1	1.6	2.1	2.6	3.1	3.7									2
8	1.9	3.9	5.9	7.9	9.8	11.8	13.8	15.7								4
9	3.6	7.6	11.6	15.6	19.6	23.6	27.6	31.6	35.6							3
10		11.9	18.3	24.8	31.2	37.6	44.0	50.4	56.8							2
11		16.8	25.9	35.1	44.2	53.4	62.5	71.7	80.8	90.0						2
12		22.1	34.3	46.5	58.7	70.9	83.1	95.2	107.4	119.6						2
13		27.9	43.4	58.9	74.4	89.9	105.4	120.9	136.4	151.9	167.4					2
14		34.1	53.2	72.3	91.4	110.5	129.6	148.7	167.8	186.9	206.0					3
15			63.7	86.7	109.6	132.6	155.5	178.5	201.4	224.4	247.4	270.3				3
16			74.9	102.0	129.1	156.2	183.3	210.4	237.4	264.5	291.6	318.7				2
17			86.9	118.3	149.8	181.3	212.8	244.3	275.7	307.2	338.7	370.2	401.7			1
18			99.5	135.7	171.8	207.9	244.1	280.2	316.4	352.5	388.6	424.8	460.9			2
19			112.9	153.9	195.0	236.1	277.2	318.2	359.3	400.4	441.4	482.5	523.6	564.6		0
20				173.2	219.5	265.8	312.0	358.3	404.6	450.8	497.1	543.4	589.6	635.9		2
21				193.5	245.2	297.0	348.7	400.4	452.1	503.9	555.6	607.3	659.1	710.8	762.5	1
22				214.7	272.2	329.7	387.1	444.6	502.1	559.5	617.0	674.5	731.9	789.4	846.9	1
23				237.0	300.5	363.9	427.4	490.9	554.3	617.8	681.3	744.7	808.2	871.7	935.1	2
24				260.2	330.0	399.7	469.4	539.2	608.9	678.7	748.4	818.1	887.9	957.6	1027.3	0
25					360.7	437.0	513.3	589.6	665.9	742.1	818.4	894.7	971.0	1047.2	1123.5	0
26					392.8	475.9	559.0	642.1	725.1	808.2	891.3	974.4	1057.5	1140.6	1223.7	1
27					426.1	516.3	606.4	696.6	786.8	876.9	967.1	1057.3	1147.4	1237.6	1327.8	1
28					460.7	558.2	655.7	753.2	850.8	948.3	1045.8	1143.3	1240.8	1338.3	1435.9	1
29					496.5	601.7	706.8	811.9	917.1	1022.2	1127.4	1232.5	1337.6	1442.8	1547.9	0
30						646.7	759.7	872.7	985.8	1098.8	1211.8	1324.9	1437.9	1550.9	1663.9	0
31						693.2	814.4	935.6	1056.8	1178.0	1299.2	1420.4	1541.6	1662.8	1783.9	1
32						741.3	870.9	1000.6	1130.2	1259.8	1389.4	1519.1	1648.7	1778.3	1907.9	0
33						791.0	929.3	1067.6	1205.9	1344.3	1482.6	1620.9	1759.3	1897.6	2035.9	1
34						842.1	989.4	1136.7	1284.0	1431.3	1578.6	1726.0	1873.3	2020.6	2167.9	1
35							1051.4	1208.0	1364.5	1521.1	1677.6	1834.2	1990.7	2147.2	2303.8	0
36							1115.2	1281.3	1447.3	1613.4	1779.5	1945.5	2111.6	2277.7	2443.7	0
37							1180.8	1356.7	1532.5	1708.4	1884.2	2060.1	2235.9	2411.8	2587.6	0
38							1248.2	1434.1	1620.1	1806.0	1991.9	2177.8	2363.7	2549.6	2735.5	0
39							1317.5	1513.7	1710.0	1906.2	2102.4	2298.7	2494.9	2691.2	2887.4	1
40								1595.4	1802.2	2009.1	2215.9	2422.8	2629.6	2836.4	3043.3	0
41								1679.1	1896.9	2114.6	2332.3	2550.0	2767.7	2985.4	3203.2	0
42								1765.0	1993.8	2222.7	2451.6	2680.4	2909.3	3138.2	3367.0	0
43								1852.9	2093.2	2333.5	2573.8	2814.0	3054.3	3294.6	3534.9	0
44								1942.9	2194.9	2446.9	2698.8	2950.8	3202.8	3454.7	3706.7	0
45									2299.0	2562.9	2826.8	3090.8	3354.7	3618.6	3882.6	0
46									2405.4	2681.6	2957.7	3233.9	3510.1	3786.2	4062.4	0
47									2514.2	2802.9	3091.6	3380.2	3668.9	3957.5	4246.2	0
48									2625.4	2926.8	3228.3	3529.7	3831.1	4132.6	4434.0	0
49									2738.9	3053.4	3367.9	3682.4	3996.9	4311.4	4625.8	0
50									2854.8	3182.6	3510.4	3838.2	4166.0	4493.8	4821.6	0
BASIS																
			2	4	6	5	3	1	1	0	0	0	0			

SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.6	1.1	1.6	2.0	2.3	2.6	3.0									4
8	1.9	3.9	5.7	7.3	8.6	9.9	11.3	12.8								5
9	3.6	7.5	11.2	14.4	17.1	19.7	22.5	25.5	28.6							3
10		11.7	17.6	22.8	27.2	31.3	35.8	40.6	45.5							2
11		16.5	24.9	32.3	38.4	44.3	50.7	57.4	64.5	71.7						3
12		21.7	32.9	42.6	50.8	58.6	66.9	75.9	85.2	94.7						0
13		27.4	41.6	53.9	64.2	73.9	84.4	95.8	107.6	119.6	131.7					5
14		33.5	50.9	66.0	78.5	90.4	103.1	116.9	131.3	146.0	160.8					5
15			60.9	78.9	93.7	107.7	122.9	139.3	156.5	174.0	191.7	209.4				3
16			71.5	92.6	109.8	126.1	143.7	162.8	182.8	203.3	224.0	244.7				6
17			82.8	107.1	126.7	145.2	165.3	187.3	210.3	233.8	257.6	281.5	305.4			2
18			94.7	122.3	144.4	165.1	187.8	212.6	238.7	265.5	292.4	319.5	346.7			2
19			107.2	138.2	162.8	185.8	211.0	238.7	268.0	297.9	328.2	358.7	389.2	419.7		0
20				154.9	181.9	207.0	234.7	265.4	297.8	331.1	364.8	398.6	432.5	466.4		3
21				172.2	201.6	228.6	258.8	292.4	328.1	364.8	401.8	439.1	476.5	513.8	551.2	1
22				190.1	221.7	250.6	283.2	319.7	358.6	398.6	439.1	479.8	520.5	561.5	602.4	1
23				208.6	242.3	272.9	307.6	346.9	388.9	432.3	476.2	520.4	564.7	609.0	653.3	2
24				227.6	263.1	295.1	331.8	373.8	418.9	465.9	512.8	560.4	608.1	655.8	703.5	
25					284.2	317.2	355.6	400.1	448.1	497.9	548.5	599.3	650.2	701.4	752.5	
26					305.3	336.9	376.7	426.4	476.2	529.0	580.7	636.7	690.9	745.1	799.4	
27					326.3	356.9	400.7	449.4	503.7	556.3	614.9	671.4	728.0	786.3	843.5	1
28					345.9	380.1	421.2	471.9	527.0	585.2	644.4	704.1	764.0	824.0	884.1	
29					367.1	398.9	440.0	491.3	548.4	608.9	670.5	732.6	794.9	857.3	919.8	0
30						416.2	456.3	508.1	566.6	628.6	692.3	756.4	820.7	885.1	949.6	
31						431.3	469.7	521.3	580.8	644.0	708.8	774.4	840.3	906.	971.2	1
32						443.9	479.5	530.1	590.6	653.3	719.0	785.4	852.0	918.1	984.1	1
33						453.3	484.9	533.5	592.2	654.7	721.4	788.0	855.1	922.1	988.3	1
34						458.9	485.1	530.5	587.4	649.9	714.7	780.4	846.9	913.4	979.9	
35							479.0	519.0	573.3	634.1	697.1	761.3	825.9	890.6	955.4	
36							465.5	500.3	550.0	606.7	666.5	727.7	789.4	851.1	913.0	
37							443.3	470.2	513.8	565.2	620.4	677.5	734.9	792.5	850.2	
38							410.8	427.5	463.3	508.3	557.2	607.4	659.1	710.9	762.8	
39							366.3	370.3	396.9	432.1	473.5	515.4	558.8	602.1	645.4	
40								306.5	309.0	323.9	353.6	384.1	414.7	445.3	476.0	
41								231.7	199.0	209.8	229.5	248.4	268.4	288.4	308.4	
42								94.1	62.2	55.5	59.7	64.7	69.8	74.9	79.9	
43								48.7	21.0	8.5	3.9	1.4	.5	.1	.1	
44								52.1	9.4	9.1	3.7	1.5	.5	.1	.1	
45									23.7	9.5	3.8	1.5	.5	.2	.1	
46									24.1	9.3	4.3	1.6	.5	.1	.1	
47									24.3	10.4	4.2	1.7	.7	.1	.1	
48									25.3	10.6	4.4	1.8	.7	.1	.1	
49									22.9	11.3	4.6	1.8	.7	.1	.1	
50									23.6	11.0	4.7	1.9	.7	.1	.1	
BASIC TREES	0	1	3	12	14	5	3	5	4	1	1	2	0	0	0	

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNFORKED TREES
SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.4	.7	1.1	1.4	1.8	2.1	2.4									0
8	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2								0
9	2.7	5.6	8.6	11.6	14.5	17.5	20.4	23.4	26.4							0
10		9.2	14.1	19.0	23.9	28.8	33.8	38.7	43.6							0
11		13.2	20.5	27.7	34.9	42.1	49.4	56.6	63.8	71.0						2
12		17.8	27.7	37.5	47.4	57.2	67.1	76.9	86.7	96.6						0
13		22.9	35.7	48.4	61.2	74.0	86.7	99.5	112.2	125.0	137.7					2
14		28.5	44.4	60.4	76.4	92.3	108.3	124.3	140.2	156.2	172.1					3
15			54.0	73.4	92.9	112.3	131.8	151.2	170.6	190.1	209.5	229.0				3
16			64.2	87.4	110.6	133.9	157.1	180.3	203.5	226.7	249.9	273.1				2
17			75.2	102.5	129.7	157.0	184.2	211.5	238.7	266.0	293.2	320.5	347.8			1
18			86.9	118.5	150.1	181.7	213.2	244.8	276.4	307.9	339.5	371.1	402.7			2
19			99.4	135.6	171.7	207.9	244.1	280.2	316.4	352.6	388.7	424.9	461.0	497.2		0
20				153.6	194.7	235.7	276.7	317.8	358.8	399.8	440.8	481.9	522.9	563.9		2
21				172.7	218.9	265.0	311.2	357.4	403.6	449.7	495.9	542.1	588.2	634.4	680.6	1
22				192.8	244.4	295.9	347.5	399.1	450.7	502.3	553.9	605.5	657.0	708.6	760.2	1
23				213.9	271.1	328.4	385.7	443.0	500.2	557.5	614.8	672.0	729.3	786.6	843.9	2
24				236.0	299.2	362.4	425.7	488.9	552.1	615.4	678.6	741.8	805.1	868.3	931.5	0
25					328.5	398.0	467.5	536.9	606.4	675.9	745.3	814.8	884.3	953.7	1023.2	0
26					359.2	435.1	511.1	587.1	663.0	739.0	815.0	891.0	966.9	1042.9	1118.9	1
27					391.1	473.8	556.6	639.3	722.1	804.8	887.6	970.3	1053.1	1135.8	1218.6	1
28					424.2	514.1	603.9	693.7	783.5	873.3	963.1	1052.9	1142.7	1232.5	1322.3	1
29					458.7	555.9	653.0	750.1	847.3	944.4	1041.5	1138.6	1235.8	1332.9	1430.0	0
30						599.2	703.9	808.7	913.4	1018.1	1122.9	1227.6	1332.3	1437.1	1541.8	0
31						644.1	756.7	869.3	981.9	1094.5	1207.2	1319.8	1432.4	1545.0	1657.6	1
32						690.6	811.3	932.1	1052.8	1173.6	1294.4	1415.1	1535.9	1656.6	1777.4	0
33						738.6	867.8	997.0	1126.1	1255.3	1384.5	1513.7	1642.8	1772.0	1901.2	1
34						788.2	926.1	1063.9	1201.8	1339.7	1477.5	1615.4	1753.3	1891.1	2029.0	1
35							986.2	1133.0	1279.8	1426.7	1573.5	1720.3	1867.2	2014.0	2160.9	0
36							1048.1	1204.2	1360.3	1516.3	1672.4	1828.5	1984.6	2140.6	2296.7	0
37							1111.9	1277.5	1443.1	1608.7	1774.2	1939.8	2105.4	2271.0	2436.6	0
38							1177.5	1352.9	1528.3	1703.6	1879.0	2054.4	2229.8	2405.1	2580.5	0
39							1244.9	1430.4	1615.8	1801.2	1986.7	2172.1	2357.6	2543.0	2728.4	1
40								1510.0	1705.8	1901.5	2097.3	2293.1	2488.8	2684.6	2880.4	0
41								1591.7	1798.1	2004.5	2210.8	2417.2	2623.6	2830.0	3036.4	0
42								1675.5	1892.8	2110.0	2327.3	2544.6	2761.8	2979.1	3196.3	0
43								1761.4	1989.8	2218.3	2446.7	2675.1	2903.5	3131.9	3360.4	0
44								1849.5	2089.3	2329.2	2569.0	2808.8	3048.7	3288.5	3528.4	0
45									2191.1	2442.7	2694.2	2945.8	3197.3	3448.9	3700.4	0
46									2295.4	2558.9	2822.4	3085.9	3349.5	3613.0	3876.5	0
47									2402.0	2677.7	2953.5	3229.3	3505.1	3780.8	4056.6	0
48									2510.9	2799.2	3087.5	3375.8	3664.1	3952.4	4240.7	0
49									2622.3	2923.4	3224.5	3525.6	3826.7	4127.8	4428.9	0
50									2736.0	3050.2	3364.4	3678.5	3992.7	4306.9	4621.0	0
BASIS TREES	0	0	1	3	8	4	6	5	3	1	1	0	0	0	0	

SOUTHWESTERN WHITE PINE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.4	.7	1.0	1.3	1.5	1.6	1.8									4
8	1.4	2.7	4.0	5.0	5.8	6.5	7.4	8.3								5
9	2.7	5.5	8.2	10.3	12.0	13.6	15.4	17.4	19.4							3
10		9.0	13.3	17.0	19.8	22.4	25.3	28.5	31.9							3
11		13.0	19.4	24.7	28.7	32.5	36.7	41.4	46.4	51.5						3
12		17.4	26.2	33.3	38.8	43.8	49.5	55.8	62.6	69.5						0
13		22.4	33.7	42.9	49.9	56.2	63.4	71.6	80.2	89.1	98.1					5
14		27.8	41.9	53.3	61.8	69.6	78.5	88.5	99.1	110.1	121.3					5
15			50.8	64.5	74.7	83.9	94.5	106.4	119.2	132.5	145.9	159.3				3
16			60.3	76.5	88.4	99.0	111.3	125.3	140.3	155.9	171.7	187.6				6
17			70.5	89.3	102.8	114.8	128.8	144.9	162.3	180.3	198.5	216.9	235.3			3
18			81.3	102.7	117.8	131.2	146.9	165.1	184.9	205.3	226.1	247.0	268.0			2
19			92.7	116.9	133.5	148.1	165.4	185.7	207.9	230.8	254.2	277.7	301.3	324.9		1
20				131.7	149.7	165.3	184.1	206.5	231.0	256.5	282.5	308.6	334.9	361.1		3
21				147.0	166.3	182.7	202.9	227.3	254.1	282.1	310.7	339.4	368.3	397.1	426.0	1
22				162.9	183.2	200.2	221.5	247.7	276.8	307.3	338.3	369.6	401.0	432.5	464.0	1
23				179.3	200.3	217.5	239.7	267.6	298.8	331.5	365.0	398.8	432.7	466.6	500.6	2
24				196.0	217.4	234.4	257.2	286.4	319.5	354.5	390.3	426.3	462.6	498.8	535.2	1
25					234.4	250.6	273.6	303.9	338.7	375.6	413.4	451.7	490.0	528.5	567.0	2
26					251.1	266.0	288.5	319.6	355.8	394.3	434.0	474.1	514.4	554.7	595.1	1
27					267.3	280.1	301.6	332.9	370.0	410.0	451.1	492.7	534.6	576.9	619.6	1
28					282.8	292.5	312.3	343.3	380.9	421.7	463.9	506.7	549.7	592.9	636.4	1
29					297.2	302.9	320.1	350.0	387.6	428.7	471.5	514.3	558.1	602.1	646.3	1
30						310.7	324.3	352.4	389.1	430.0	472.7	515.7	560.0	603.9	647.9	1
31						315.4	324.1	349.4	384.5	424.3	466.2	508.0	550.2	592.5	636.8	1
32						316.3	316.7	340.0	372.5	410.4	450.7	491.9	533.4	575.4	617.3	1
33						312.7	307.2	323.1	351.8	386.7	424.2	462.3	500.7	541.4	580.8	1
34						303.6	288.3	297.3	320.9	351.4	385.0	419.9	455.3	491.0	526.7	1
35							260.7	261.0	277.8	302.6	330.8	360.5	390.4	421.4	451.6	1
36							223.0	212.4	220.5	237.7	258.9	281.7	304.7	328.1	350.9	1
37							173.3	149.3	146.7	154.3	166.4	180.4	194.7	210.3	225.5	1
38							109.7	69.4	53.4	49.0	49.8	52.7	56.2	60.6	65.0	1
39							56.9	38.4	16.2	5.7	2.7	1.1	.4	.2	.1	1
40								40.5	17.1	7.0	2.9	1.1	.5	.2	.1	
41								42.7	18.0	7.4	3.0	1.2	.5	.2	.1	
42								44.9	19.0	7.8	3.2	1.3	.5	.2	.1	1
43								47.3	19.9	8.2	3.3	1.3	.5	.2	.1	
44								49.6	20.9	8.6	3.5	1.4	.5	.2	.1	
45									22.0	9.0	3.7	1.5	.6	.2	.1	
46									23.0	9.5	3.8	1.5	.6	.2	.1	
47									24.1	9.9	4.0	1.6	.6	.2	.1	
48									25.2	10.4	4.2	1.7	.6	.2	.1	
49									26.3	10.8	4.4	1.8	.7	.2	.1	
50									27.4	11.3	4.6	1.8	.7	.2	.1	
BASIS TREES	3	1	3	12	14	5	5	6	6	1	1	1				

TOTAL STEM GROSS CUBIC FOOT VOLUME-UNFORKED TREES
ENGELMANN SPRUCE-CORKBARK FIR
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.2															0
2	.3	.4														0
3	.4	.6	.8													0
4	.6	.9	1.3	1.6												0
5	.8	1.3	1.9	2.4	2.9											17
6	1.0	1.8	2.6	3.3	4.1	4.9										23
7	1.3	2.4	3.4	4.5	5.5	6.6	7.7									17
8	1.6	3.0	4.4	5.8	7.2	8.6	9.9	11.3								12
9	2.0	3.7	5.5	7.3	9.0	10.8	12.5	14.3	16.0							15
10		4.6	6.7	8.9	11.1	13.2	15.4	17.6	19.8							14
11		5.5	8.1	10.7	13.4	16.0	18.6	21.2	23.9	26.5						10
12		6.5	9.6	12.7	15.8	19.0	22.1	25.2	28.3	31.5						5
13		7.6	11.2	14.9	18.6	22.2	25.9	29.6	33.2	36.9	40.6					4
14		8.7	13.0	17.2	21.5	25.7	30.0	34.2	38.5	42.8	47.0					3
15			14.9	19.8	24.6	29.5	34.4	39.3	44.2	49.0	53.9	58.8				5
16			16.9	22.4	28.0	33.6	39.1	44.7	50.2	55.8	61.3	66.9				5
17			19.0	25.3	31.6	37.8	44.1	50.4	56.7	62.9	69.2	75.5	81.7			3
18			21.3	28.3	35.4	42.4	49.4	56.5	63.5	70.5	77.6	84.6	91.6			2
19			23.7	31.6	39.4	47.2	55.1	62.9	70.7	78.6	86.4	94.2	102.0	109.9		1
20				34.9	43.6	52.3	61.0	69.7	78.3	87.0	95.7	104.4	113.0	121.7		4
21				38.5	48.1	57.6	67.2	76.8	86.3	95.9	105.5	115.0	124.6	134.2	143.8	1
22				42.2	52.7	63.2	73.7	84.2	94.7	105.2	115.7	126.2	136.7	147.2	157.7	1
23				46.1	57.6	69.1	80.6	92.0	103.5	115.0	126.5	138.0	149.4	160.9	172.4	0
24				50.2	62.7	75.2	87.7	100.2	112.7	125.2	137.7	150.2	162.7	175.2	187.7	0
25					68.0	81.6	95.1	108.7	122.3	135.8	149.4	163.0	176.5	190.1	203.6	0
26					73.6	88.2	102.9	117.6	132.2	146.9	161.6	176.2	190.9	205.6	220.2	0
27					79.3	95.1	110.9	126.8	142.6	158.4	174.2	190.0	205.8	221.7	237.5	0
28					85.3	102.3	119.3	136.3	153.3	170.3	187.3	204.4	221.4	238.4	255.4	0
29					91.5	109.7	128.0	146.2	164.5	182.7	200.9	219.2	237.4	255.7	273.9	0
30						117.4	136.9	156.4	176.0	195.5	215.0	234.6	254.1	273.6	293.1	0
31						125.3	146.2	167.0	187.9	208.7	229.6	250.4	271.3	292.1	313.0	0
32						133.5	155.7	178.0	200.2	222.4	244.6	266.8	289.1	311.3	333.5	0
33						142.0	165.6	189.2	212.9	236.5	260.1	283.8	307.4	331.0	354.6	0
34						150.7	175.8	200.9	226.0	251.0	276.1	301.2	326.3	351.4	376.5	0
35							186.3	212.9	239.4	266.0	292.6	319.2	345.8	372.3	398.9	0
36							197.1	225.2	253.3	281.4	309.5	337.7	365.8	393.9	422.0	0
37							208.1	237.9	267.6	297.3	327.0	356.7	386.4	416.1	445.8	0
38							219.5	250.9	282.2	313.5	344.9	376.2	407.5	438.9	470.2	0
39							231.2	264.2	297.2	330.2	363.2	396.2	429.2	462.2	495.2	0
40								277.9	312.7	347.4	382.1	416.8	451.5	486.2	521.0	0
41								292.0	328.5	365.0	401.4	437.9	474.4	510.8	547.3	0
42								306.4	344.7	383.0	421.2	459.5	497.8	536.1	574.3	0
43								321.2	361.3	401.4	441.5	481.6	521.8	561.9	602.0	0
44								336.3	378.3	420.3	462.3	504.3	546.3	588.3	630.3	0
45									395.7	439.6	483.5	527.5	571.4	615.3	659.3	0
46									413.4	459.3	505.2	551.2	597.1	643.0	688.9	0
47									431.6	479.5	527.4	575.4	623.3	671.2	719.2	0
48									450.1	500.1	550.1	600.1	650.1	700.1	750.1	0
49									469.1	521.2	573.3	625.4	677.5	729.5	781.6	0
50									488.4	542.7	596.9	651.1	705.4	759.6	813.9	0

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.2															0
2	.3	.4														0
3	.4	.6	.8													0
4	.6	.9	1.2	1.6												0
5	.7	1.3	1.8	2.3	2.9											15
6	1.0	1.7	2.5	3.3	4.0	4.8										20
7	1.2	2.3	3.3	4.3	5.4	6.5	7.6									17
8	1.5	2.9	4.2	5.6	6.9	8.4	9.8	11.3								13
9	1.9	3.6	5.3	7.0	8.7	10.5	12.3	14.2	16.0							21
10		4.3	6.4	8.5	10.6	12.8	15.1	17.4	19.8							11
11		5.2	7.7	10.2	12.7	15.3	18.1	20.9	23.9	26.5						13
12		6.1	9.1	12.0	15.0	18.1	21.3	24.7	28.2	31.5						3
13		7.1	10.5	14.0	17.4	21.0	24.7	28.6	32.8	36.9	40.6					3
14		8.2	12.1	16.0	20.0	24.1	28.3	32.8	37.6	42.8	47.0					3
15			13.8	18.2	22.7	27.3	32.1	37.2	42.6	48.5	53.9	58.8				3
16			15.5	20.5	25.5	30.7	36.0	41.7	47.8	54.4	61.3	66.9				3
17			17.4	22.9	28.4	34.1	40.0	46.3	53.0	60.4	68.4	75.2	81.7			3
18			19.3	25.4	31.4	37.6	44.1	50.9	58.4	66.5	75.3	84.6	91.6			4
19			21.3	27.9	34.5	41.2	48.2	55.6	63.7	72.6	82.3	92.8	102.0	109.9		1
20				30.5	37.6	44.8	52.3	60.3	69.1	78.7	89.2	100.6	113.0	121.7		3
21				33.1	40.7	48.4	56.4	65.0	74.4	84.7	96.0	108.3	121.8	134.1	143.8	1
22				35.8	43.8	51.9	60.4	69.6	79.6	90.6	102.7	116.0	130.3	145.8	157.7	1
23				38.5	46.9	55.5	64.4	74.1	84.7	96.4	109.3	123.4	138.7	155.6	172.4	
24				41.1	50.0	59.2	68.3	78.4	89.7	102.1	115.7	130.7	146.8	164.2	183.1	
25					53.0	62.9	72.2	82.6	94.5	107.5	121.9	137.7	154.7	173.1	192.9	
26					56.0	66.4	75.9	86.7	99.0	112.8	127.9	144.4	162.3	181.6	202.4	
27					58.7	69.5	78.9	90.5	103.4	117.8	133.6	150.9	169.6	189.7	211.4	
28					61.5	71.4	82.1	94.1	107.6	122.5	139.0	157.0	176.5	197.4	220.0	
29					64.0	74.1	85.1	97.5	111.4	127.0	144.1	162.7	182.9	204.7	228.0	
30						76.7	87.9	100.7	115.1	131.1	148.8	168.1	189.0	211.5	235.6	
31						79.1	90.5	103.6	118.4	135.0	153.2	173.1	194.7	217.8	242.6	
32						81.3	92.8	106.2	121.9	138.9	157.8	177.7	199.8	223.6	249.0	
33						83.1	94.9	108.6	124.2	141.7	161.1	181.7	204.1	228.8	254.9	
34						84.9	96.8	110.7	126.7	144.5	164.1	185.1	208.2	233.0	260.1	
35							98.4	112.6	128.9	147.3	167.2	188.5	212.1	237.3	264.7	
36							99.8	114.2	130.8	149.4	169.8	191.4	215.7	241.4	269.6	
37							101.0	115.5	132.4	151.3	171.9	194.0	218.5	244.5	273.2	
38							101.9	116.7	133.8	152.8	173.7	196.0	220.7	247.0	276.0	
39							102.6	117.5	134.7	154.1	175.1	198.0	222.5	249.0	278.2	
40								118.2	135.6	155.2	176.5	199.5	224.5	251.2	280.7	
41								118.6	136.1	155.9	177.4	200.6	225.8	252.7	282.5	
42								118.9	136.3	156.3	177.9	201.3	226.7	253.8	283.8	
43								118.7	136.4	156.4	178.1	201.5	227.0	254.2	284.4	
44								118.5	136.2	156.2	177.9	201.4	226.9	254.1	284.3	
45									135.7	155.8	177.5	200.9	226.5	253.7	283.8	
46									135.1	154.9	176.5	199.8	225.3	252.4	282.4	
47									134.3	153.7	175.1	198.3	223.7	250.7	280.5	
48									133.3	152.3	173.5	196.5	221.8	248.7	278.3	
49									132.2	151.0	172.0	194.9	220.0	246.8	276.2	
50									131.0	149.7	170.6	193.4	218.4	245.1	274.4	
ALL																
TREES	0	3	14	42	71	94	113	93	77	51	31	15	7	3	1	

TOTAL STEM NET CUBIC FOOT VOLUME
CORKBARK FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.2															0
2	.3	.4														0
3	.4	.6	.8													0
4	.6	.9	1.2	1.5												0
5	.8	1.3	1.8	2.3	2.7											0
6	1.0	1.8	2.5	3.2	3.8	4.5										3
7	1.3	2.3	3.3	4.2	5.1	6.0	6.8									4
8	1.6	3.0	4.3	5.5	6.6	7.7	8.8	9.8								1
9	2.0	3.7	5.4	6.9	8.3	9.7	11.0	12.2	13.4							4
10		4.6	6.6	8.5	10.2	11.9	13.5	15.0	16.4							4
11		5.5	8.0	10.3	12.4	14.4	16.3	18.0	19.7	21.3						2
12		6.5	9.6	12.3	14.8	17.2	19.4	21.5	23.4	25.3						5
13		7.6	11.2	14.5	17.5	20.3	22.9	25.3	27.6	29.7	31.7					3
14		8.7	13.0	16.9	20.4	23.7	26.7	29.6	32.2	34.7	37.0					0
15			14.9	19.5	23.6	27.4	30.9	34.2	37.3	40.2	42.9	45.4				2
16			16.9	22.3	27.0	31.4	35.5	39.3	42.9	46.3	49.4	52.3				2
17			19.0	25.3	30.7	35.8	40.5	44.9	49.0	52.9	56.5	59.8	62.9			0
18			21.3	28.3	34.7	40.4	45.8	50.8	55.6	60.0	64.1	68.0	71.6			2
19			23.7	31.6	38.9	45.4	51.5	57.2	62.6	67.7	72.4	76.9	81.0	84.9		0
20				34.9	43.4	50.7	57.5	64.0	70.1	75.9	81.3	86.4	91.1	95.6		1
21				38.5	48.1	56.3	64.0	71.2	78.1	84.6	90.7	96.5	101.9	107.0	111.8	0
22				42.2	52.7	62.1	70.7	78.9	86.5	93.8	100.7	107.2	113.4	119.2	124.6	0
23				46.1	57.6	68.3	77.8	86.9	95.4	103.6	111.3	118.6	125.5	132.0	138.2	0
24				50.2	62.7	74.8	85.3	95.3	104.8	113.8	122.4	130.6	138.3	145.6	152.6	0
25					68.0	81.6	93.1	104.1	114.6	124.6	134.1	143.1	151.8	159.9	167.7	0
26					73.6	88.2	101.3	113.4	124.9	135.9	146.3	156.3	165.9	174.9	183.6	0
27					79.3	95.1	109.8	123.0	135.6	147.6	159.1	170.1	180.6	190.6	200.2	0
28					85.3	102.3	118.7	133.0	146.7	159.9	172.5	184.5	196.0	207.0	217.6	0
29					91.5	109.7	127.9	143.4	158.3	172.6	186.3	199.5	212.1	224.2	235.7	0
30						117.4	136.9	154.2	170.4	185.9	200.8	215.1	228.8	242.0	254.6	0
31						125.3	146.2	165.4	182.9	199.6	215.7	231.2	246.1	260.4	274.2	0
32						133.5	155.7	177.1	195.8	213.9	231.2	248.0	264.1	279.6	294.6	0
33						142.0	165.6	189.1	209.2	228.6	247.3	265.4	282.8	299.5	315.7	0
34						150.7	175.8	200.9	223.0	243.8	263.9	283.3	302.0	320.1	337.5	0
35							186.3	212.9	237.3	259.5	281.1	301.9	322.0	341.4	360.1	0
36							197.1	225.2	252.0	275.8	298.8	321.0	342.5	363.3	383.4	0
37							208.1	237.9	267.2	292.5	317.0	340.7	363.7	386.0	407.5	0
38							219.5	250.9	282.2	309.7	335.8	361.1	385.6	409.3	432.3	0
39							231.2	264.2	297.2	327.4	355.1	382.0	408.1	433.4	457.9	0
40								277.9	312.7	345.6	375.0	403.5	431.2	458.1	484.2	0
41								292.0	328.5	364.3	395.4	425.6	455.0	483.5	511.2	0
42								306.4	344.7	383.0	416.4	448.3	479.4	509.6	539.0	0
43								321.2	361.3	401.4	437.9	471.6	504.5	536.4	567.5	0
44								336.3	378.3	420.3	459.9	495.5	530.2	563.9	596.8	0
45									395.7	439.6	482.5	520.0	556.5	592.1	626.8	0
46									413.4	459.3	505.2	545.1	583.5	621.0	657.5	0
47									431.6	479.5	527.4	570.8	611.2	650.6	689.0	0
48									450.1	500.1	550.1	597.0	639.4	680.8	721.2	0
49									469.1	521.2	573.3	623.9	668.4	711.8	754.2	0
50									488.4	542.7	596.9	651.1	697.9	743.5	787.9	0

SANTA FE-CARSON-CINCHER N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.5	.7	.9	1.1	1.3											17
6	.7	1.3	1.8	2.3	2.8	3.3										29
7	1.0	1.8	2.7	3.5	4.4	5.2	6.1									17
8	1.2	2.4	3.7	4.9	6.1	7.3	8.5	9.7								12
9	1.5	3.1	4.7	6.3	8.0	9.6	11.2	12.8	14.4							23
10		3.8	5.9	7.9	10.0	12.0	14.1	16.1	18.2							14
11		4.6	7.1	9.7	12.2	14.7	17.2	19.7	22.3	24.8						10
12		5.5	8.5	11.5	14.6	17.6	20.6	23.7	26.7	29.7						9
13		6.4	10.0	13.6	17.2	20.7	24.3	27.9	31.5	35.1	38.7					4
14		7.4	11.6	15.7	19.9	24.1	28.3	32.5	36.6	40.8	45.0					3
15			13.3	18.1	22.9	27.7	32.5	37.3	42.1	47.0	51.8	56.6				5
16			15.1	20.6	26.1	31.5	37.0	42.5	48.0	53.5	59.0	64.5				5
17			17.0	23.2	29.4	35.6	41.8	48.1	54.3	60.5	66.7	72.9	79.1			2
18			19.0	26.0	33.0	40.0	46.9	53.9	60.9	67.9	74.8	81.8	88.8			1
19			21.2	29.0	36.7	44.5	52.3	60.1	67.9	75.7	83.4	91.2	99.0	106.8		1
20				32.1	40.7	49.3	58.0	66.6	75.2	83.9	92.5	101.1	109.8	118.4		4
21				35.3	44.9	54.4	63.9	73.4	83.0	92.5	102.0	111.5	121.1	130.6	140.1	1
22				38.7	49.2	59.7	70.1	80.6	91.1	101.5	112.0	122.5	132.9	143.4	153.8	1
23				42.3	53.8	65.2	76.7	88.1	99.5	111.0	122.4	133.9	145.3	156.8	168.2	1
24				46.1	58.5	71.0	83.5	95.9	108.4	120.9	133.3	145.8	158.2	170.7	183.1	1
25					63.5	77.0	90.6	104.1	117.6	131.1	144.7	158.2	171.7	185.2	198.8	1
26					68.7	83.3	97.9	112.6	127.2	141.8	156.4	171.1	185.8	200.4	215.0	
27					74.0	89.8	105.6	121.4	137.2	153.0	168.8	184.6	200.4	216.1	231.9	
28					79.6	96.6	113.6	130.5	147.5	164.5	181.5	198.5	215.5	232.5	249.4	
29					85.4	103.6	121.8	140.0	158.2	176.5	194.7	212.9	231.1	249.4	267.6	
30						110.8	130.2	149.8	169.2	188.8	208.3	227.8	247.3	266.9	286.4	
31						118.3	139.1	160.0	180.8	201.6	222.5	243.3	264.1	284.9	305.8	
32						126.1	148.3	170.5	192.6	214.8	237.1	259.	281.4	303.6	325.8	
33						134.0	157.7	181.3	204.9	228.5	252.1	275.7	299.3	322.9	346.5	
34						142.3	167.3	192.4	217.5	242.5	267.6	292.6	317.7	342.8	367.8	
35							177.3	203.9	230.4	257.0	283.5	310.1	336.7	363.2	389.8	
36							187.6	215.7	243.8	271.9	300.0	328.1	356.2	384.3	412.4	
37							198.1	227.8	257.4	287.1	316.7	346.4	376.	405.6	435.3	
38							209.0	240.3	271.6	302.9	334.2	365.5	396.8	428.1	459.5	
39							220.1	253.1	286.1	319.0	352.	385.	418.	451.	484.	
40								266.2	300.9	335.6	370.3	405.0	439.7	474.4	509.	
41								279.7	316.1	352.5	388.9	425.3	461.8	498.2	534.6	
42								293.6	331.7	370.0	408.3	446.5	484.8	523.	561.	
43								307.5	347.7	387.6	427.9	468.1	508.	548.	588.	
44								322.0	364.0	406.	448.1	490.	532.	574.	616.	
45									380.8	424.8	468.8	513.	557.	601.	645.	
46									397.9	443.8	489.8	536.	582.	628.	674.	
47									415.3	463.2	511.	559.	607.	655.	703.	
48									433.0	483.0	533.1	583.1	633.	683.	733.	
49									451.4	503.7	556.0	608.	660.	712.	764.	
50									470.0	524.	578.5	633.	687.	741.	795.	

BASIS TREES

NET CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES
ENGELMANN SPRUCE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.5	.7	.8	1.0	1.2											15
6	.7	1.2	1.7	2.2	2.7	3.2										20
7	.9	1.7	2.6	3.4	4.2	5.1	6.0									17
8	1.2	2.3	3.5	4.6	5.8	7.1	8.3	9.7								19
9	1.4	2.9	4.5	6.0	7.6	9.2	10.9	12.6	14.4							21
10		3.6	5.6	7.5	9.5	11.5	13.6	15.9	18.2							11
11		4.4	6.7	9.1	11.5	14.0	16.6	19.4	22.3	24.8						12
12		5.1	8.0	10.8	13.7	16.7	19.8	23.1	26.6	29.7						3
13		6.0	9.3	12.6	16.0	19.5	23.1	27.0	31.3	35.1	38.7					3
14		6.9	10.7	14.6	18.5	22.5	26.7	31.2	36.1	40.8	45.0					3
15			12.2	16.6	21.1	25.6	30.5	35.6	41.3	47.0	51.8	56.6				3
16			13.8	18.8	23.8	28.9	34.4	40.2	46.6	53.5	59.0	64.5				3
17			15.5	21.0	26.6	32.4	38.4	45.0	52.2	60.1	66.7	72.9	79.1			3
18			17.2	23.4	29.5	35.9	42.6	49.9	57.9	66.8	74.8	81.8	88.8			4
19			19.1	25.8	32.6	39.5	46.9	54.9	63.8	73.6	83.4	91.2	99.0	106.8		1
20				28.3	35.7	43.3	51.3	60.1	69.8	80.6	92.5	101.1	109.8	118.4		3
21				30.9	38.8	47.0	55.8	65.3	75.9	87.7	100.7	111.5	121.1	130.6	140.1	1
22				33.5	42.1	50.9	60.3	70.6	82.1	94.8	109.0	122.5	132.9	143.4	153.8	1
23				36.2	45.3	54.8	64.9	76.0	88.3	102.1	117.4	133.9	145.3	156.8	168.2	0
24				38.9	48.6	58.7	69.5	81.3	94.6	109.4	125.7	143.8	158.2	170.7	183.2	0
25					52.0	62.6	74.0	86.7	100.9	116.6	134.1	153.4	171.7	185.3	198.8	0
26					55.3	66.5	78.6	92.1	107.1	123.9	142.5	163.0	185.4	200.4	215.0	0
27					58.6	70.4	83.2	97.4	113.4	131.1	150.8	172.5	196.2	216.1	231.9	0
28					61.9	74.2	87.7	102.7	119.5	138.3	159.1	182.0	206.9	232.4	249.4	0
29					65.2	78.0	92.1	107.9	125.7	145.4	167.3	191.3	217.5	246.1	267.6	0
30						81.7	96.5	113.1	131.7	152.5	175.4	200.5	228.0	257.9	286.4	0
31						85.4	100.8	118.2	137.7	159.4	183.3	209.6	238.3	269.4	303.4	0
32						89.0	105.0	123.1	143.5	166.2	191.1	218.5	248.3	280.8	316.0	0
33						92.5	109.1	128.0	149.2	172.8	198.8	227.2	258.1	291.8	328.3	0
34						95.9	113.2	132.8	154.8	179.3	206.2	235.7	267.7	302.5	340.3	0
35							117.1	137.4	160.3	185.6	213.5	243.9	277.0	312.9	351.9	0
36							120.9	142.0	165.6	191.8	220.5	251.9	286.0	323.0	363.2	0
37							124.6	146.3	170.8	197.8	227.4	259.6	294.7	332.7	374.0	0
38							128.2	150.6	175.7	203.5	234.0	267.1	303.1	342.1	384.3	0
39							131.7	154.7	180.6	209.1	240.3	274.3	311.1	351.0	394.2	0
40								158.7	185.2	214.5	246.4	281.1	318.8	359.6	403.7	0
41								162.5	189.7	219.6	252.3	287.7	326.1	367.7	412.6	0
42								166.2	194.0	224.6	257.9	294.0	333.1	375.4	421.1	0
43								169.8	198.2	229.3	263.2	300.0	339.7	382.7	429.1	0
44								173.2	202.1	233.8	268.3	305.7	346.0	389.6	436.7	0
45									205.9	238.1	273.1	311.0	351.9	396.1	443.7	0
46									209.5	242.2	277.7	316.1	357.5	402.1	450.3	0
47									212.9	246.1	282.1	320.9	362.7	407.8	456.3	0
48									216.2	249.8	286.2	325.3	367.5	413.0	462.0	0
49									219.3	253.3	290.0	329.5	372.1	417.9	467.2	0
50									222.3	256.6	293.6	333.5	376.3	422.4	471.9	0
BASIS TREES	0	3	36	39	19	16	13	8	3	1	0	0	0	0	0	

CORKBARK FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.5	.7	.8	1.0	1.2											2
6	.7	1.2	1.7	2.1	2.6	3.0										3
7	1.0	1.8	2.6	3.3	4.0	4.7	5.4									4
8	1.2	2.4	3.6	4.6	5.6	6.5	7.4	8.3								1
9	1.5	3.1	4.6	6.0	7.3	8.5	9.7	10.8	11.9							4
10		3.8	5.8	7.5	9.2	10.7	12.2	13.6	14.9							4
11		4.6	7.1	9.3	11.3	13.2	14.9	16.6	18.1	19.6						2
12		5.5	8.5	11.1	13.6	15.9	18.0	19.9	21.8	23.5						5
13		6.4	10.0	13.2	16.1	18.8	21.2	23.7	25.8	27.8	29.7					3
14		7.4	11.6	15.5	18.9	22.1	25.0	27.8	30.3	32.7	34.8					0
15			13.3	17.9	21.9	25.7	29.1	32.3	35.3	38.0	40.5	42.9				2
16			15.1	20.6	25.2	29.5	33.5	37.2	40.7	43.9	46.8	49.6				2
17			17.0	23.2	28.7	33.7	38.3	42.6	46.6	50.3	53.7	56.9	59.8			1
18			19.0	26.0	32.5	38.2	43.4	48.4	52.9	57.2	61.2	64.9	68.3			2
19			21.2	29.0	36.5	42.9	48.9	54.5	59.8	64.7	69.2	73.5	77.4	81.1		0
20				32.1	40.7	48.0	54.8	61.1	67.1	72.7	77.9	82.7	87.3	91.5		1
21				35.3	44.9	53.3	60.9	68.1	74.8	81.1	87.1	92.6	97.8	102.6	107.1	1
22				38.7	49.2	59.0	67.5	75.5	83.0	90.1	96.8	103.1	109.0	114.5	119.6	
23				42.3	53.8	64.9	74.3	83.3	91.7	99.6	107.1	114.2	120.8	127.1	132.9	
24				46.1	58.5	71.0	81.5	91.4	100.8	109.6	118.0	125.9	133.3	140.4	147.0	
25					63.5	77.0	89.1	100.0	110.3	120.1	129.4	138.2	146.5	154.3	161.8	
26					68.7	83.3	97.0	108.9	120.3	131.1	141.3	151.1	160.3	169.2	177.3	
27					74.0	89.8	105.2	118.2	130.7	142.6	153.8	164.7	174.8	184.4	193.6	
28					79.6	96.6	113.6	128.0	141.6	154.5	166.9	178.7	189.9	200.5	210.7	
29					85.4	103.6	121.8	138.1	152.8	167.1	180.5	193.3	205.6	217.3	228.5	
30						110.8	130.3	148.5	164.6	179.9	194.6	208.6	222.0	234.8	247.0	
31						116.3	139.1	159.4	176.7	193.1	209.3	224.4	238.7	252.6	265.3	
32						121.9	148.3	170.5	189.1	207.0	224.4	240.4	255.7	271.0	284.3	
33						134.0	157.7	181.8	202.4	221.6	240.1	257.3	273.6	289.4	304.1	
34						142.3	167.3	193.4	215.9	236.5	256.4	274.6	292.0	308.9	324.6	
35							177.3	205.2	229.8	252.4	273.6	293.2	311.8	329.8	346.6	
36							187.6	215.7	243.8	267.6	291.0	311.9	331.7	350.8	368.9	
37							198.1	227.8	257.5	284.2	308.4	331.9	353.0	373.5	393.0	
38							209.0	240.3	271.6	300.1	326.9	351.9	374.5	396.4	417.3	
39							220.1	253.1	286.1	318.3	345.8	372.1	396.2	419.5	441.8	
40								266.2	300.9	335.5	365.3	393.5	418.9	443.8	467.5	
41								279.7	316.1	352.1	385.1	414.9	441.8	468.2	493.4	
42								293.4	331.7	370.0	404.9	436.4	465.0	492.8	519.5	
43								307.4	347.7	387.8	425.0	458.1	488.4	517.6	545.7	
44								321.6	364.0	406.0	445.3	480.0	512.0	542.6	572.1	
45									380.6	424.4	465.8	502.1	535.8	568.0	598.8	
46									397.4	443.0	486.5	524.4	560.0	593.6	625.8	
47									415.3	462.8	508.3	548.0	585.4	620.5	654.1	
48									433.5	483.0	530.4	572.0	611.2	648.0	683.0	
49									451.9	503.6	553.1	596.4	637.4	675.9	712.5	
50									470.5	524.4	576.5	621.3	664.1	704.3	742.5	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES-UNFORKED TREES
ENGELMANN SPRUCE-CORKBARK FIR
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.5	.8	1.2	1.5	1.9	2.2	2.6									16
8	.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4								12
9	1.2	2.4	3.7	5.0	6.2	7.5	8.8	10.0	11.3							[illegible]
10		3.3	5.0	6.8	8.5	10.3	12.0	13.8	15.5							14
11		4.1	6.4	8.6	10.9	13.2	15.4	17.7	20.0	22.2						[illegible]
12		5.0	7.8	10.6	13.5	16.3	19.1	21.9	24.7	27.5						5
13		6.0	9.4	12.8	16.2	19.5	22.9	26.3	29.7	33.1	36.5					[illegible]
14		7.0	11.0	15.0	19.0	23.0	27.0	31.0	35.0	39.0	43.0					3
15			12.8	17.4	22.1	26.7	31.4	36.1	40.7	45.4	50.0	54.7				2
16			14.6	20.0	25.3	30.7	36.0	41.4	46.7	52.1	57.4	62.8				2
17			16.6	22.7	28.8	34.8	40.9	47.0	53.1	59.2	65.2	71.3	77.4			3
18			18.7	25.5	32.4	39.2	46.1	52.9	59.8	66.6	73.5	80.4	87.2			[illegible]
19			20.8	28.5	36.2	43.8	51.5	59.2	66.9	74.5	82.2	89.9	97.6	105.2		1
20				31.6	40.2	48.7	57.2	65.8	74.3	82.8	91.4	99.9	108.4	117.0		4
21				34.9	44.4	53.8	63.2	72.7	82.1	91.5	101.0	110.4	119.8	129.2	138.7	1
22				38.4	48.8	59.1	69.5	79.9	90.3	100.6	111.0	121.4	131.7	142.1	152.5	1
23				42.0	53.3	64.7	76.1	87.4	98.8	110.1	121.5	132.9	144.2	155.6	166.9	0
24				45.8	58.1	70.5	82.9	95.3	107.7	120.1	132.4	144.8	157.2	169.6	182.0	0
25					63.1	76.6	90.0	103.5	116.9	130.4	143.8	157.3	170.8	184.2	197.7	0
26					68.3	82.9	97.4	112.0	126.6	141.1	155.7	170.3	184.8	199.4	214.0	0
27					73.7	89.4	105.1	120.9	136.6	152.3	168.0	183.7	199.5	215.2	230.9	0
28					79.3	96.2	113.1	130.0	147.0	163.9	180.8	197.7	214.6	231.6	248.5	0
29					85.1	103.2	121.4	139.5	157.7	175.9	194.0	212.2	230.4	248.5	266.7	0
30						110.5	129.9	149.4	168.8	188.3	207.7	227.2	246.6	266.1	285.5	0
31						118.0	138.8	159.5	180.3	201.1	221.9	242.6	263.4	284.2	305.0	0
32						125.8	147.9	170.0	192.2	214.3	236.5	258.6	280.8	302.9	325.1	0
33						133.7	157.3	180.9	204.4	228.0	251.5	275.1	298.7	322.2	345.8	0
34						142.0	167.0	192.0	217.0	242.1	267.1	292.1	317.1	342.1	367.1	0
35							177.0	203.5	230.0	256.5	283.1	309.6	336.1	362.6	389.1	0
36							187.3	215.3	243.4	271.4	299.5	327.6	355.6	383.7	411.7	0
37							197.8	227.5	257.1	286.8	316.4	346.1	375.7	405.3	435.0	0
38							208.7	240.0	271.2	302.5	333.8	365.0	396.3	427.6	458.9	0
39							219.8	252.8	285.7	318.7	351.6	384.6	417.5	450.4	483.4	0
40								265.9	300.6	335.2	369.9	404.6	439.2	473.9	508.5	0
41								279.4	315.8	352.2	388.6	425.1	461.5	497.9	534.3	0
42								293.2	331.4	369.6	407.9	446.1	484.3	522.5	560.8	0
43								307.3	347.4	387.5	427.5	467.6	507.7	547.7	587.8	0
44								321.8	363.7	405.7	447.7	489.6	531.6	573.5	615.5	0
45									380.5	424.4	468.3	512.2	556.0	599.9	643.8	0
46									397.6	443.5	489.3	535.2	581.1	626.9	672.8	0
47									415.1	463.0	510.8	558.7	606.6	654.5	702.4	0
48									432.9	482.9	532.8	582.8	632.7	682.7	732.6	0
49									451.2	503.2	555.3	607.3	659.4	711.4	763.5	0
50									469.8	524.0	578.2	632.4	686.6	740.8	795.0	0
BASIS TREES	0	2	20	35	27	20	17	9	2	1	0	0	0	0	0	

NET CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES
ENGELMANN SPRUCE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BA/A
7	.5	.8	1.1	1.5	1.8	2.2	2.5									17
8	.8	1.5	2.3	3.1	3.9	4.7	5.5	6.4								19
9	1.1	2.3	3.5	4.7	5.9	7.2	8.4	9.9	11.3							21
10		3.1	4.7	6.4	8.1	9.8	11.6	13.5	15.5							21
11		3.9	6.0	8.1	10.3	12.5	14.9	17.3	20.0	22.2						22
12		4.7	7.3	10.0	12.6	15.4	18.2	21.3	24.6	27.5						4
13		5.6	8.7	11.9	15.1	18.3	21.8	25.4	29.4	33.1	36.5					4
14		6.5	10.2	13.9	17.6	21.4	25.5	29.7	34.4	39.0	43.0					3
15			11.8	16.0	20.2	24.7	29.3	34.2	39.6	45.4	50.3	54.7				1
16			13.4	18.2	23.0	28.0	33.3	38.9	45.1	51.9	57.4	62.6				1
17			15.1	20.5	25.9	31.5	37.4	43.7	50.6	58.3	65.2	71.3	77.4			2
18			16.9	22.9	28.9	35.0	41.6	48.6	56.4	65.1	73.5	80.4	87.2			4
19			18.7	25.3	31.9	38.7	45.9	53.6	62.2	71.7	80.1	88.1	97.5	106.3		1
20				27.8	35.0	42.4	50.2	58.7	68.2	78.4	88.2	99.9	108.4	116.1		
21				30.4	38.2	46.2	54.6	63.9	74.1	85.5	96.3	110.4	119.4	129.7	138.2	1
22				33.0	41.4	50.0	59.1	69.1	80.2	92.7	105.1	121.4	131.7	144.1	155.2	
23				35.7	44.6	53.8	63.6	74.3	86.2	99.6	114.4	133.2	144.8	159.6	172.6	
24				38.4	47.8	57.6	68.2	79.5	92.3	106.5	122.9	140.9	157.8	174.6	190.6	
25					51.1	61.4	72.9	84.7	98.4	113.4	131.9	148.5	166.7	189.6	207.7	
26					54.4	65.2	76.9	89.4	104.4	120.4	138.9	156.2	176.0	194.6	214.0	
27					57.6	68.9	81.3	94.4	110.3	127.4	146.4	164.2	185.3	204.7	225.0	
28					61.8	72.6	85.9	99.8	116.4	134.3	154.1	173.4	194.7	215.0	236.1	
29					62.9	76.3	89.7	104.3	121.8	140.4	161.9	182.0	204.3	225.6	247.4	
30						79.8	93.9	109.2	127.4	147.0	169.4	190.4	213.8	236.4	259.0	
31						83.2	98.2	114.1	133.2	153.6	177.0	199.0	223.4	247.1	270.8	
32						86.6	102.4	119.1	139.1	160.4	184.7	207.6	233.0	257.8	282.6	
33						90.0	106.7	124.0	145.0	167.2	192.4	216.3	242.7	268.5	294.4	
34						93.4	110.9	129.0	150.8	174.0	200.2	225.0	252.4	279.2	306.2	
35							115.2	133.9	156.7	180.8	208.0	233.7	262.1	289.9	318.0	
36							119.4	138.9	162.5	187.6	215.8	242.5	271.8	300.7	329.8	
37							123.7	143.8	168.4	194.4	223.6	251.2	281.6	311.5	341.7	
38							127.9	148.8	174.2	201.1	231.4	259.9	291.3	322.3	353.5	
39							132.2	153.7	180.0	207.9	239.2	268.7	301.1	333.1	365.4	
40							136.4	158.7	185.8	214.7	247.0	277.4	310.9	344.0	377.3	
41							140.7	163.6	191.6	221.4	254.8	286.2	320.7	354.8	389.2	
42							144.9	168.6	197.4	228.2	262.6	294.9	330.5	365.6	401.1	
43							149.2	173.5	203.2	235.0	270.4	303.7	340.3	376.4	413.0	
44							153.4	178.5	209.0	241.7	278.2	312.4	350.1	387.2	424.9	
45							157.7	183.4	214.8	248.5	286.0	321.2	359.9	398.0	436.8	
46							161.9	188.4	220.6	255.3	293.8	329.9	369.7	408.8	448.7	
47							166.2	193.3	226.4	262.0	301.6	338.7	379.5	419.6	460.6	
48							170.4	198.3	232.2	268.8	309.4	347.4	389.3	430.4	472.5	
49								203.2	238.0	275.6	317.2	356.2	399.1	441.2	484.4	
50								208.2	243.8	282.3	325.0	364.9	408.9	452.0	496.3	

NET CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES
CORKBARK FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.5	.8	1.1	1.4	1.7	1.9	2.2									4
8	.8	1.6	2.4	3.0	3.6	4.2	4.7	5.3								1
9	1.2	2.4	3.6	4.6	5.6	6.5	7.3	8.1	8.8							4
10		3.3	5.0	6.4	7.7	8.9	10.0	11.0	12.0							4
11		4.1	6.4	8.3	9.9	11.5	12.9	14.1	15.3	16.4						2
12		5.0	7.8	10.3	12.4	14.3	16.0	17.5	18.9	20.2						5
13		6.0	9.4	12.5	15.1	17.4	19.4	21.3	22.9	24.4	25.8					3
14		7.0	11.0	15.0	18.0	20.8	23.2	25.4	27.4	29.2	30.7					2
15			12.8	17.4	21.2	24.5	27.4	30.0	32.4	34.4	36.3	37.9				1
16			14.6	20.0	24.7	28.5	32.0	35.1	37.8	40.3	42.4	44.4				2
17			16.6	22.7	28.4	32.9	36.9	40.5	43.8	46.6	49.2	51.5	53.5			0
18			18.7	25.5	32.4	37.6	42.3	46.5	50.2	53.6	56.6	59.3	61.7			2
19			20.8	28.5	36.2	42.6	48.0	52.8	57.2	61.2	64.7	67.8	70.7	73.2		0
20				31.6	40.2	47.9	54.1	59.6	64.7	69.2	73.4	77.1	80.4	83.3		1
21				34.9	44.4	53.6	60.5	66.9	72.6	77.9	82.7	86.9	90.8	94.3	97.4	0
22				38.4	48.8	59.1	67.4	74.5	81.1	87.1	92.6	97.5	102.0	106.0	109.6	0
23				42.0	53.3	64.7	74.6	82.6	90.0	96.8	103.1	108.7	113.9	118.5	122.8	0
24				45.8	58.1	70.5	82.1	91.2	99.5	107.1	114.2	120.6	126.5	131.8	136.7	0
25					63.1	76.6	90.0	100.1	109.4	118.0	125.9	133.1	139.8	145.9	151.5	0
26					68.3	82.9	97.4	109.5	119.8	129.3	138.1	146.3	153.8	160.7	167.0	0
27					73.7	89.4	105.1	119.2	130.6	141.2	151.0	160.1	168.5	176.3	183.4	0
28					79.3	96.2	113.1	129.4	142.0	153.6	164.5	174.6	183.9	192.6	200.6	0
29					85.1	103.2	121.4	139.5	153.8	166.6	178.5	189.7	200.0	209.7	218.6	0
30						110.5	129.9	149.4	166.0	180.0	193.1	205.4	216.8	227.5	237.4	0
31						118.0	138.8	159.5	178.8	194.0	208.4	221.8	234.3	246.1	257.0	0
32						125.8	147.9	170.0	192.0	208.6	224.2	238.8	252.5	265.4	277.4	0
33						133.7	157.3	180.9	204.4	223.6	240.5	256.4	271.4	285.4	298.6	0
34						142.0	167.0	192.0	217.0	239.2	257.5	274.7	291.0	306.3	320.6	0
35							177.0	203.5	230.0	255.4	275.0	293.7	311.2	327.8	343.4	0
36							187.3	215.3	243.4	271.4	293.2	313.2	332.2	350.1	367.1	0
37							197.8	227.5	257.1	286.8	311.9	333.4	353.8	373.2	391.5	0
38							208.7	240.0	271.2	302.5	331.2	354.3	376.2	397.0	416.7	0
39							219.8	252.8	285.7	318.7	351.1	375.8	399.2	421.5	442.7	0
40								265.9	300.6	335.2	369.9	397.9	423.0	446.8	469.5	0
41								279.4	315.8	352.2	388.6	420.6	447.4	472.9	497.1	0
42								293.2	331.4	369.6	407.9	444.0	472.5	499.7	525.6	0
43								307.3	347.4	387.5	427.5	467.6	498.3	527.2	554.8	0
44								321.8	363.7	405.7	447.7	489.6	524.8	555.5	584.8	0
45									380.5	424.4	468.3	512.2	552.0	584.5	615.6	0
46									397.6	443.5	489.3	535.2	579.9	614.3	647.3	0
47									415.1	463.0	510.8	558.7	606.6	644.9	679.7	0
48									432.9	482.9	532.8	582.8	632.7	676.1	713.0	0
49									451.2	503.2	555.3	607.3	659.4	708.2	747.0	0
50									469.8	524.0	578.2	632.4	686.6	740.8	781.9	0
BASIS TREES	0	0	9	5	9	7	5	0	0	0	0	0	0	0	0	

GROSS INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB-UNFORKED TREES
ENGELMANN SPRUCE-CORKBARK FIR
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	1.1	2.0	2.8	3.6	4.5	5.3	6.1									14
8	3.2	6.3	9.4	12.5	15.7	18.8	21.9	25.0								12
9	5.4	11.4	17.3	23.3	29.2	35.1	41.1	47.0	53.0							29
10		16.8	25.8	34.8	43.8	52.9	61.9	70.9	80.0							14
11		22.4	34.7	47.0	59.2	71.5	83.8	96.1	108.4	120.7						13
12		28.2	43.9	59.6	75.4	91.1	106.8	122.5	138.3	154.0						5
13		34.3	53.6	72.9	92.3	111.6	130.9	150.2	169.6	188.9	208.2					4
14		40.7	63.8	86.9	110.0	133.1	156.2	179.3	202.4	225.5	248.7					2
15			74.4	101.5	128.6	155.7	182.8	209.9	237.0	264.1	291.2	318.3				5
16			85.6	116.9	148.2	179.4	210.7	242.0	273.3	304.6	335.9	367.1				4
17			97.3	133.0	168.7	204.4	240.1	275.8	311.5	347.1	382.8	418.5	454.2			3
18			109.7	150.0	190.3	230.6	270.9	311.2	351.5	391.8	432.1	472.5	512.8			5
19			122.6	167.8	213.0	258.1	303.2	348.4	393.6	438.7	483.9	529.1	574.2	619.4		1
20				186.4	236.6	286.9	337.1	387.4	437.6	487.9	538.1	588.4	638.6	688.8		4
21				205.9	261.4	317.0	372.6	428.1	483.7	539.3	594.8	650.4	706.0	761.5	817.1	1
22				226.2	287.4	348.5	409.6	470.7	531.9	593.0	654.1	715.3	776.4	837.5	898.6	1
23				247.5	314.4	381.3	448.3	515.2	582.1	649.1	716.0	782.9	849.9	916.8	983.7	1
24				269.6	342.6	415.6	488.5	561.5	634.5	707.5	780.5	853.4	926.4	999.4	1072.4	1
25					371.9	451.2	530.5	609.7	689.0	768.3	847.6	926.8	1006.1	1085.4	1164.7	1
26					402.4	488.2	574.0	659.8	745.7	831.5	917.3	1003.1	1088.9	1174.6	1260.6	1
27					434.0	526.5	619.3	711.9	804.5	897.1	989.7	1082.3	1174.9	1267.5	1360.1	1
28					466.9	566.3	665.8	765.8	865.5	965.1	1064.8	1164.4	1264.1	1363.7	1463.4	1
29					500.8	607.8	714.7	821.7	928.6	1035.6	1142.5	1249.5	1356.4	1463.4	1570.3	1
30						650.5	765.0	879.5	994.0	1108.5	1223.0	1337.5	1451.9	1566.4	1680.9	1
31						694.5	816.9	939.2	1061.6	1183.8	1306.1	1428.4	1550.7	1673.0	1795.3	1
32						740.2	870.5	1000.9	1131.2	1261.5	1391.9	1522.3	1652.6	1782.9	1913.3	1
33						787.0	925.4	1063.8	1202.2	1341.8	1481.4	1619.1	1757.8	1896.5	2035.1	1
34						835.7	982.9	1130.1	1277.3	1424.5	1571.8	1719.0	1866.2	2013.4	2160.6	1
35							1041.6	1197.6	1353.7	1509.7	1665.8	1821.8	1977.8	2133.9	2289.9	1
36							1102.0	1267.1	1432.2	1597.4	1762.5	1927.6	2092.7	2257.8	2422.9	1
37							1164.1	1338.2	1513.0	1687.7	1862.4	2036.9	2211.5	2386.0	2560.6	1
38							1228.0	1411.2	1596.0	1780.1	1964.1	2148.1	2332.2	2516.2	2700.2	1
39							1293.6	1487.4	1681.3	1875.1	2069.0	2262.8	2456.7	2650.5	2844.4	1
40								1565.2	1768.7	1972.2	2175.7	2379.2	2582.7	2786.2	2989.7	1
41								1644.1	1858.4	2072.6	2286.9	2501.1	2715.4	2929.6	3143.9	1
42								1725.8	1950.3	2174.8	2399.3	2623.8	2848.3	3072.8	3297.3	1
43								1809.4	2044.4	2279.4	2514.4	2749.4	2984.4	3219.4	3454.4	1
44								1894.6	2140.8	2387.0	2633.2	2879.4	3125.6	3371.8	3618.0	1
45									2238.8	2496.1	2753.4	3010.7	3268.0	3525.3	3782.6	1
46									2338.4	2606.7	2875.0	3143.3	3411.6	3679.9	3948.2	1
47									2439.6	2719.0	2998.4	3277.8	3557.2	3836.6	4116.0	1
48									2542.4	2832.9	3123.4	3413.9	3704.4	3994.9	4285.4	1
49									2646.8	2948.4	3250.0	3551.6	3853.2	4154.8	4456.4	1
50									2752.8	3065.0	3377.2	3689.4	4001.6	4313.8	4626.0	1

NET INTERNATIONAL BOARD FOOT VOLUME IN A INCH TOP DIB
ENGELMANN SPRUCE
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	1.0	1.7	2.5	3.2	3.9	4.7	5.4									17
8	2.8	5.5	8.2	10.9	13.6	16.3	19.0	21.7								12
9	4.6	9.7	14.7	19.8	24.8	29.9	34.9	40.0	45.1							22
10		14.0	21.5	29.1	36.6	44.1	51.7	59.2	66.7							11
11		18.3	28.3	38.4	48.5	58.5	68.6	78.6	88.7	98.7						12
12		22.6	35.2	47.8	60.4	72.9	85.5	98.1	110.7	123.3						3
13		26.9	42.0	57.2	72.3	87.5	102.6	117.7	132.9	148.0	163.2					3
14		31.2	48.9	66.6	84.3	102.1	119.8	137.5	155.2	172.9	190.7					3
15			55.8	76.2	96.5	116.8	137.1	157.5	177.8	198.1	218.4	238.8				3
16			62.8	85.8	108.8	131.8	154.7	177.7	200.7	223.6	246.6	269.6				3
17			70.0	95.6	121.3	147.0	172.6	198.3	223.9	249.6	275.3	300.9	326.6			3
18			77.3	105.7	134.1	162.5	190.9	219.3	247.7	276.1	304.5	332.9	361.3			4
19			84.8	116.0	147.2	178.4	209.7	240.9	272.1	303.3	334.6	365.8	397.0	428.2		1
20				126.6	160.7	194.8	229.0	263.1	297.2	331.3	365.5	399.6	433.7	467.8		2
21				137.5	174.6	211.8	248.9	286.0	323.1	360.2	397.3	434.5	471.6	508.7	545.8	1
22				148.8	189.1	229.3	269.5	309.7	349.9	390.1	430.4	470.6	510.8	551.0	591.2	1
23				160.6	204.0	247.4	290.9	334.3	377.7	421.2	464.6	508.0	551.5	594.9	638.3	0
24				172.8	219.6	266.3	313.1	359.9	406.6	453.4	500.2	547.0	593.7	640.5	687.3	0
25					235.7	286.0	336.2	386.4	436.7	486.9	537.2	587.4	637.7	687.9	738.2	0
26					252.5	306.4	360.3	414.1	468.0	521.8	575.7	629.5	683.4	737.3	791.1	0
27					270.0	327.7	385.3	442.9	500.5	558.1	615.7	673.4	731.0	788.6	846.2	0
28					288.2	349.8	411.3	472.8	534.4	595.9	657.4	719.0	780.5	842.0	903.5	0
29					307.2	372.8	438.4	504.0	569.6	635.2	700.8	766.3	831.9	897.5	963.1	0
30						396.7	466.5	536.3	606.1	675.9	745.8	815.6	885.4	955.2	1025.0	0
31						421.5	495.7	569.9	644.1	718.3	792.5	866.7	940.9	1015.1	1089.3	0
32						447.2	525.9	604.7	683.4	762.2	840.9	919.7	998.4	1077.2	1155.9	0
33						473.8	557.3	640.7	724.2	807.7	891.1	974.6	1058.0	1141.5	1225.0	0
34						501.4	589.7	678.1	766.4	854.7	943.0	1031.4	1119.7	1208.0	1296.4	0
35							623.2	716.6	810.0	903.3	996.7	1090.1	1183.4	1276.8	1370.2	0
36							657.9	756.4	855.0	953.6	1052.1	1150.7	1249.3	1347.8	1446.4	0
37							693.6	797.5	901.4	1005.3	1109.3	1213.2	1317.1	1421.1	1525.0	0
38							730.3	839.8	949.2	1058.7	1168.2	1277.6	1387.1	1496.5	1606.0	0
39							768.2	883.3	998.5	1113.6	1228.8	1343.9	1459.0	1574.2	1689.3	0
40								928.1	1049.1	1170.1	1291.1	1412.1	1533.1	1654.1	1775.1	0
41								974.2	1101.2	1228.2	1355.2	1482.2	1609.2	1736.2	1863.2	0
42								1021.4	1154.6	1287.8	1420.9	1554.1	1687.3	1820.4	1953.6	0
43								1069.9	1209.4	1348.9	1488.4	1627.9	1767.4	1906.9	2046.4	0
44								1119.6	1265.6	1411.6	1557.6	1703.6	1849.6	1995.6	2141.5	0
45									1323.2	1475.8	1628.4	1781.1	1933.7	2086.4	2239.0	0
46									1382.1	1541.5	1701.0	1860.4	2019.9	2179.3	2338.8	0
47									1442.4	1608.8	1775.2	1941.6	2108.0	2274.5	2440.9	0
48									1504.1	1677.6	1851.1	2024.7	2198.2	2371.7	2545.3	0
49									1567.1	1747.9	1928.7	2109.5	2290.3	2471.2	2652.0	0
50									1631.4	1819.7	2008.0	2196.2	2384.5	2572.7	2761.0	0
BASIS TREES	0	0	12	31	20	16	12	9	2	1	0	0	0	0	0	

NET INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB
CORKBARK FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.9	1.5	2.2	2.8	3.5	4.1	4.8									4
8	2.3	4.6	6.9	9.2	11.5	13.8	16.1	18.4								1
9	3.7	7.8	11.9	16.0	20.1	24.2	28.3	32.4	36.5							4
10		10.8	16.7	22.5	28.3	34.1	40.0	45.8	51.6							4
11		13.6	21.0	28.5	35.9	43.4	50.8	58.2	65.7	73.1						5
12		16.1	25.1	34.1	43.1	52.0	61.0	70.0	79.0	88.0						6
13		18.6	29.1	39.5	50.0	60.5	71.0	81.5	91.9	102.4	112.9					3
14		21.1	33.1	45.1	57.0	69.0	81.0	93.0	105.0	117.0	129.0					3
15			37.2	50.8	64.3	77.9	91.4	105.0	118.6	132.1	145.7	159.2				3
16			41.6	56.8	72.0	87.2	102.4	117.7	132.9	148.1	163.3	178.5				1
17			46.3	63.2	80.2	97.2	114.2	131.1	148.1	165.1	182.0	199.0	216.0			3
18			51.3	70.1	89.0	107.8	126.7	145.5	164.3	183.2	202.0	220.9	239.7			3
19			56.6	77.4	98.2	119.1	140.0	160.8	181.7	202.5	223.4	244.2	265.1	285.9		4
20				85.0	108.2	131.3	154.3	177.3	200.1	223.1	246.1	269.1	292.1	315.1		1
21				93.5	118.7	144.0	169.2	194.5	219.7	244.9	270.2	295.4	320.7	345.9	371.1	
22				102.2	129.9	157.5	185.1	212.7	240.4	268.0	295.6	323.3	350.9	378.5	406.2	
23				111.4	141.6	171.7	201.8	232.0	262.1	292.3	322.4	352.6	382.7	412.8	442.9	
24				121.1	153.8	186.6	219.4	252.2	284.9	317.7	350.5	383.3	416.0	448.8	481.6	
25					166.7	202.2	237.8	273.3	308.8	344.2	379.9	415.4	451.4	486.9	522.5	
26					180.1	218.5	256.9	295.2	333.7	372.1	410.5	448.9	487.4	525.8	564.2	
27					194.1	235.5	276.8	318.2	359.7	401.1	442.5	483.9	525.3	566.7	608.1	
28					208.6	253.1	297.6	342.2	386.7	431.2	475.8	520.3	564.7	609.2	653.6	
29					223.7	271.4	319.0	366.7	414.3	461.9	509.5	557.1	604.7	652.3	699.9	
30						290.4	341.5	392.6	443.7	494.7	545.8	596.9	647.9	699.0	750.0	
31						310.3	364.8	419.3	473.7	528.2	582.7	637.2	691.7	746.2	800.7	
32						330.7	388.4	446.1	503.8	561.5	619.1	676.8	734.5	792.2	849.8	
33						351.6	413.1	474.6	536.1	597.6	659.1	720.6	782.1	843.6	905.1	
34						373.0	438.3	503.6	568.9	634.2	699.5	764.8	830.1	895.4	960.7	
35							464.2	533.4	602.7	671.9	741.2	810.4	879.7	948.9	1018.2	
36							491.0	564.1	637.3	710.4	783.6	856.7	929.9	1003.0	1076.2	
37							518.3	595.7	673.1	750.4	827.8	905.1	982.5	1059.8	1137.2	
38							546.2	628.0	709.8	791.6	873.4	955.2	1037.0	1118.8	1200.6	
39								660.8	747.0	833.2	919.4	1005.6	1091.8	1178.0	1264.2	
40								694.1	784.5	875.0	965.4	1055.9	1146.3	1236.8	1327.2	
41								728.0	823.0	917.9	1012.8	1107.8	1202.7	1297.7	1392.6	
42								762.4	862.1	961.7	1061.4	1161.0	1260.7	1360.3	1460.0	
43								797.4	901.8	1006.1	1110.5	1214.8	1319.2	1423.5	1527.9	
44								832.9	942.0	1051.1	1160.2	1269.3	1378.4	1487.5	1596.6	
45								869.0	982.7	1096.4	1210.1	1323.8	1437.5	1551.2	1664.9	
46								905.6	1024.0	1142.4	1260.8	1379.2	1497.6	1616.0	1734.4	
47								942.8	1065.9	1189.0	1312.1	1435.2	1558.3	1681.4	1804.5	
48								980.5	1108.4	1236.3	1364.2	1492.1	1620.0	1747.9	1875.8	
49								1018.8	1151.5	1284.2	1416.9	1549.6	1682.3	1815.0	1947.7	
50								1057.4	1195.2	1332.9	1470.7	1608.4	1746.2	1883.9	2021.7	

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNFORKED TREES
ENGELMANN SPRUCE-CORKBARK FIR
SANTA FE-CARSON-LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASAL AREA
7	.6	1.1	1.6	2.0	2.5	2.9	3.4									0
8	2.0	4.0	5.9	7.9	9.8	11.8	13.8	15.7								0
9	3.7	7.7	11.8	15.8	19.9	23.9	28.0	32.0	36.1							11
10		12.0	18.5	25.0	31.5	38.0	44.5	51.0	57.4							14
11		16.7	25.9	35.0	44.2	53.4	62.6	71.7	80.9	90.1						10
12		21.6	33.7	45.8	57.8	69.9	82.0	94.0	106.1	118.2						5
13		26.9	42.0	57.2	72.3	87.5	102.6	117.8	132.9	148.0	163.2					4
14		32.4	50.8	69.2	87.6	106.1	124.5	142.9	161.3	179.7	198.1					3
15			60.1	82.0	103.8	125.7	147.6	169.4	191.3	213.2	235.1	256.9				5
16			69.8	95.4	120.9	146.4	171.9	197.5	223.0	248.5	274.0	299.6				4
17			80.1	109.5	138.9	168.2	197.6	227.0	256.4	285.7	315.1	344.5	373.8			3
18			90.9	124.3	157.8	191.2	224.6	258.0	291.4	324.9	358.3	391.7	425.1			2
19			102.3	139.9	177.6	215.3	252.9	290.6	328.3	366.0	403.6	441.3	479.0	516.6		1
20				156.3	198.4	240.5	282.7	324.8	366.9	409.0	451.2	493.3	535.4	577.6		4
21				173.4	220.2	267.0	313.8	360.6	407.4	454.2	501.0	547.8	594.6	641.4	688.2	1
22				191.2	242.9	294.6	346.3	398.0	449.6	501.3	553.0	604.7	656.4	708.0	759.7	1
23				209.9	266.7	323.4	380.2	437.0	493.8	550.5	607.3	664.1	720.9	777.6	834.4	0
24				229.3	291.4	353.5	415.6	477.7	539.8	601.8	663.9	726.0	788.1	850.2	912.3	0
25					317.2	384.8	452.4	520.0	587.6	655.2	722.8	790.5	858.1	925.7	993.3	0
26					344.0	417.3	490.7	564.0	637.4	710.7	784.1	857.5	930.8	1004.2	1077.5	0
27					371.8	451.1	530.4	609.7	689.0	768.4	847.7	927.0	1006.3	1085.6	1165.0	0
28					400.6	486.1	571.6	657.1	742.6	828.1	913.6	999.1	1084.6	1170.1	1255.6	0
29					430.4	522.3	614.3	706.2	798.1	890.0	981.9	1073.8	1165.7	1257.7	1349.6	0
30						559.9	658.4	756.9	855.5	954.0	1052.6	1151.1	1249.7	1348.2	1446.7	0
31						598.6	704.0	809.4	914.8	1020.2	1125.6	1231.0	1336.4	1441.8	1547.2	0
32						638.7	751.1	863.6	976.1	1088.5	1201.0	1313.5	1425.9	1538.4	1650.9	0
33						680.0	799.7	919.5	1039.3	1159.0	1278.8	1398.6	1518.3	1638.1	1757.9	0
34						722.5	849.8	977.1	1104.4	1231.7	1359.0	1486.3	1613.5	1740.8	1868.1	0
35							901.4	1036.4	1171.5	1306.5	1441.5	1576.6	1711.6	1846.6	1981.7	0
36							954.5	1097.5	1240.5	1383.5	1526.5	1669.5	1812.5	1955.5	2098.5	0
37							1009.0	1160.2	1311.4	1462.6	1613.8	1765.1	1916.3	2067.5	2218.7	0
38							1065.1	1224.7	1384.4	1544.0	1703.6	1863.2	2022.9	2182.5	2342.1	0
39							1122.7	1291.0	1459.2	1627.5	1795.8	1964.0	2132.3	2300.6	2468.8	0
40								1358.9	1536.0	1713.2	1890.3	2067.5	2244.6	2421.8	2598.9	0
41								1428.6	1614.8	1801.1	1987.3	2173.5	2359.8	2546.0	2732.3	0
42								1500.0	1695.6	1891.1	2086.7	2282.3	2477.8	2673.4	2869.0	0
43								1573.1	1778.2	1983.4	2188.5	2393.6	2598.7	2803.8	3008.9	0
44								1648.0	1862.9	2077.8	2292.7	2507.6	2722.5	2937.4	3152.3	0
45									1949.5	2174.4	2399.3	2624.2	2849.1	3074.0	3298.9	0
46									2038.1	2273.2	2508.3	2743.5	2978.6	3213.7	3448.9	0
47									2128.6	2374.2	2619.8	2865.4	3111.0	3356.5	3602.1	0
48									2221.1	2477.4	2733.7	2989.9	3246.2	3502.5	3758.7	0
49									2315.6	2582.8	2849.9	3117.1	3384.3	3651.5	3918.7	0
50									2412.0	2690.3	2968.6	3247.0	3525.3	3803.6	4081.9	0
BASIS TREES	0	0	3	7	18	17	14	9	2	1	0	0	0	0	0	

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.6	1.0	1.4	1.8	2.2	2.6	3.0									17
8	1.7	3.4	5.1	6.8	8.5	10.1	11.8	13.5								17
9	3.1	6.5	10.0	13.4	16.8	20.2	23.6	27.0	30.5							22
10		10.0	15.3	20.7	26.1	31.4	36.8	42.2	47.5							11
11		13.5	21.0	28.4	35.8	43.2	50.7	58.1	65.5	73.0						17
12		17.1	26.7	36.3	45.8	55.4	64.9	74.5	84.0	93.6						3
13		20.8	32.5	44.3	56.0	67.7	79.5	91.2	102.9	114.6	126.4					3
14		24.5	38.4	52.4	66.3	80.3	94.2	108.1	122.1	136.0	149.9					2
15			44.4	60.6	76.8	92.9	109.1	125.3	141.5	157.6	173.8	190.0				3
16			50.5	68.9	87.4	105.8	124.3	142.7	161.2	179.6	198.1	216.5				3
17			56.6	77.4	98.2	118.9	139.7	160.5	181.2	202.0	222.7	243.5	264.3			3
18			62.9	86.0	109.2	132.3	155.4	178.5	201.7	224.8	247.9	271.0	294.2			4
19			69.3	94.9	120.4	146.0	171.5	197.1	222.6	248.2	273.7	299.2	324.8	350.3		1
20				104.0	132.0	160.0	188.1	216.1	244.1	272.1	300.2	328.2	356.2	384.3		3
21				113.3	143.9	174.5	205.1	235.7	266.3	296.9	327.5	358.1	388.8	419.2	449.8	1
22				123.0	156.2	189.5	222.7	256.0	289.2	322.4	355.7	388.9	422.1	455.4	488.6	1
23				133.0	169.0	205.0	241.0	277.0	312.9	348.9	384.9	420.9	456.9	492.8	528.8	1
24				143.4	182.5	221.1	259.9	298.7	337.6	376.4	415.2	454.0	492.9	531.7	570.5	
25					196.0	237.8	279.6	321.4	363.2	404.9	446.7	488.5	530.3	572.1	613.9	
26					210.3	255.2	300.1	344.9	389.8	434.6	479.5	524.4	569.2	614.1	658.9	
27					225.2	273.3	321.4	369.4	417.5	465.5	513.6	561.6	609.7	657.8	705.8	
28					240.7	292.1	343.5	394.9	446.3	497.7	549.0	600.4	651.8	703.2	754.6	
29					256.8	311.7	366.5	421.4	476.2	531.0	585.9	640.7	695.6	750.4	805.3	
30						332.0	390.4	448.9	507.3	565.7	624.2	682.6	741.0	799.4	857.9	
31						353.1	415.2	477.4	539.6	601.7	663.9	726.1	788.3	850.4	912.6	
32						374.9	441.1	507.0	573.0	639.1	705.1	771.1	837.2	903.2	969.1	
33						397.6	467.6	537.7	607.7	677.7	747.8	817.8	887.9	958.0	1028.0	
34						421.1	495.2	569.4	643.6	717.8	791.9	866.1	940.3	1014.4	1088.6	
35							523.8	602.3	680.7	759.1	837.6	916.2	994.6	1073.1	1151.6	
36							553.2	636.1	719.0	801.9	884.7	967.6	1050.4	1133.3	1216.2	
37							583.6	671.0	758.5	845.9	933.4	1020.8	1108.3	1195.7	1283.1	
38							614.9	707.0	799.2	891.3	983.5	1075.6	1167.7	1259.8	1351.9	
39							647.1	744.1	841.1	938.1	1035.1	1132.1	1229.1	1326.1	1423.0	
40								782.1	884.2	986.2	1088.1	1190.1	1292.1	1394.0	1496.0	
41								821.4	928.5	1035.6	1142.7	1249.7	1356.8	1463.8	1570.9	
42								861.8	974.0	1086.3	1198.5	1311.0	1423.2	1535.3	1647.5	
43								903.3	1020.6	1138.0	1255.3	1372.8	1490.2	1607.6	1725.0	
44								945.2	1068.5	1191.7	1315.0	1438.2	1561.5	1684.8	1808.0	
45									1118.5	1246.9	1375.3	1503.7	1632.1	1760.5	1888.9	
46									1169.7	1303.4	1437.1	1571.8	1705.6	1839.3	1973.0	
47									1222.1	1361.9	1501.7	1641.6	1781.4	1921.2	2061.0	
48									1275.6	1421.6	1567.5	1713.5	1859.4	2005.4	2151.4	
49									1330.3	1482.5	1634.6	1786.8	1938.9	2091.1	2243.2	
50									1386.1	1544.6	1703.2	1861.7	2020.3	2178.8	2337.4	

NET SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB
CORKBARK FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.5	.8	1.2	1.6	1.9	2.3	2.6									4
8	1.5	2.9	4.3	5.7	7.2	8.6	10.0	11.4								4
9	2.5	5.3	8.0	10.8	13.5	16.3	19.0	21.8	24.5							4
10		7.7	11.8	15.9	20.0	24.1	28.3	32.4	36.5							4
11		9.9	15.4	20.8	26.3	31.7	37.2	42.6	48.1	53.5						3
12		12.1	18.8	25.6	32.3	39.0	45.8	52.5	59.2	66.0						3
13		14.2	22.2	30.2	38.2	46.2	54.2	62.2	70.2	78.2	86.2					3
14		16.3	25.6	34.9	44.2	53.5	62.8	72.1	81.3	90.6	99.9					2
15			29.2	39.8	50.4	61.0	71.6	82.2	92.9	103.5	114.1	124.7				2
16			32.9	44.9	56.9	68.9	80.9	93.0	105.0	117.0	129.0	141.0				1
17			36.8	50.3	63.9	77.4	90.9	104.4	117.9	131.4	144.9	158.4	171.9			0
18			41.1	56.2	71.2	86.3	101.4	116.5	131.6	146.7	161.8	176.9	192.0			0
19			45.6	62.3	79.1	95.9	112.7	129.5	146.3	163.1	179.9	196.6	213.4	230.2		0
20				68.9	87.5	106.1	124.7	143.3	161.9	180.4	199.0	217.6	236.2	254.8		0
21				75.9	96.4	116.9	137.4	157.9	178.4	198.9	219.4	239.9	260.3	280.8	301.3	0
22				83.3	105.8	128.3	150.8	173.3	195.8	218.3	240.9	263.4	285.9	308.4	330.9	0
23				91.1	115.7	140.3	165.0	189.6	214.2	238.8	263.5	288.1	312.7	337.4	362.0	0
24				99.2	126.1	152.9	179.8	206.6	233.5	260.4	287.2	314.1	340.9	367.8	394.7	0
25					136.9	166.1	195.3	224.5	253.7	282.9	312.1	341.3	370.4	399.6	428.8	0
26					148.3	179.9	211.5	243.1	274.8	306.4	338.0	369.6	401.3	432.9	464.5	0
27					160.1	194.2	228.4	262.6	296.7	330.9	365.0	399.2	433.3	467.5	501.7	0
28					172.4	209.2	245.9	282.7	319.5	356.3	393.1	429.9	466.7	503.5	540.3	0
29					185.1	224.6	264.2	303.7	343.2	382.7	422.3	461.8	501.3	540.9	580.4	0
30						240.7	283.0	325.4	367.8	410.1	452.5	494.8	537.2	579.6	621.9	0
31						257.3	302.6	347.8	393.1	438.4	483.7	529.0	574.3	619.6	664.9	0
32						274.4	322.7	371.1	419.4	467.7	516.0	564.4	612.7	661.0	709.3	0
33						292.1	343.6	395.0	446.5	497.9	549.4	600.8	652.3	703.7	755.2	0
34						310.4	365.0	419.7	474.4	529.1	583.7	638.4	693.1	747.8	802.5	0
35							387.2	445.2	503.2	561.2	619.2	677.2	735.2	793.2	851.2	0
36							409.9	471.4	532.8	594.2	655.6	717.0	778.5	839.9	901.3	0
37							433.4	498.3	563.2	628.2	693.1	758.1	823.0	887.9	952.9	0
38							457.4	526.0	594.5	663.1	731.6	800.2	868.7	937.3	1005.9	0
39							482.1	554.4	626.7	698.9	771.2	843.5	915.7	988.0	1060.3	0
40								583.6	659.7	735.7	811.8	887.9	964.0	1040.0	1116.1	0
41								613.5	693.5	773.5	853.4	933.4	1013.4	1093.4	1173.4	0
42								644.2	728.1	812.1	896.1	980.1	1064.1	1148.1	1232.1	0
43								675.6	763.7	851.7	939.8	1027.9	1116.0	1204.1	1292.2	0
44								707.7	800.0	892.3	984.6	1076.9	1169.1	1261.4	1353.7	0
45									837.2	933.8	1030.4	1126.9	1223.5	1320.1	1416.7	0
46									875.2	976.2	1077.2	1178.1	1279.1	1380.1	1481.1	0
47									914.1	1019.6	1125.0	1230.5	1336.0	1441.4	1546.9	0
48									953.8	1063.9	1173.9	1284.0	1394.0	1504.1	1614.1	0
49									994.4	1109.1	1223.9	1338.6	1453.3	1568.1	1682.8	0
50									1035.8	1155.3	1274.8	1394.4	1513.9	1633.4	1752.9	0
BASIS TREES	0	0	5	5	9	7	5	0	0	0	0	0	0	0	0	

DBH CLASS	HEIGHT CLASS															BASIC
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
1	.3															0
2	.3	.4														0
3	.4	.6	.8													0
4	.6	.9	1.3	1.7												0
5	.8	1.3	1.9	2.4	3.0											0
6	1.0	1.8	2.6	3.4	4.2	5.0										0
7	1.3	2.4	3.5	4.6	5.7	6.7	7.8									0
8	1.7	3.1	4.5	5.9	7.3	8.7	10.1	11.6								1
9	2.0	3.8	5.6	7.4	9.2	11.0	12.8	14.5	16.4							1
10		4.7	6.9	9.1	11.3	13.5	15.7	17.9	20.1							2
11		5.6	8.3	10.9	13.6	16.3	19.0	21.6	24.3	27.0						2
12		6.6	9.8	13.0	16.2	19.3	22.5	25.7	28.9	32.1						3
13		7.7	11.4	15.2	18.9	22.7	26.4	30.1	33.9	37.6	41.3					4
14		8.9	13.2	17.6	21.9	26.2	30.6	34.9	39.2	43.5	47.9					5
15			15.2	20.1	25.1	30.1	35.1	40.0	45.0	50.0	55.0	60.0				6
16			17.2	22.9	28.5	34.2	39.9	45.5	51.2	56.8	62.5	68.2				7
17			19.4	25.8	32.2	38.6	45.0	51.4	57.8	64.1	70.5	76.9	83.3			8
18			21.7	28.9	36.1	43.2	50.4	57.6	64.7	71.9	79.0	86.2	93.4			9
19			24.2	32.2	40.1	48.1	56.1	64.1	72.1	80.1	88.0	96.0	104.0	112.0		10
20				35.6	44.5	53.3	62.2	71.0	79.8	88.7	97.5	106.4	115.2	124.1		11
21				39.2	49.0	58.7	68.5	78.2	88.0	97.8	107.5	117.3	127.0	136.8	146.5	12
22				43.1	53.7	64.5	75.2	85.9	96.7	107.3	118.0	128.7	139.4	150.1	160.8	13
23				47.0	58.7	70.4	82.1	93.8	105.5	117.2	128.9	140.6	152.3	164.0	175.7	14
24				51.2	63.9	76.7	89.4	102.1	114.9	127.6	140.3	153.1	165.8	178.6	191.3	15
25					69.3	83.2	97.0	110.8	124.6	138.4	152.3	166.1	179.9	193.7	207.5	16
26					74.9	89.9	104.9	119.8	134.8	149.7	164.7	179.6	194.6	209.5	224.4	17
27					80.8	97.0	113.1	129.2	145.3	161.4	177.6	193.7	209.8	225.9	242.0	18
28					86.9	104.3	121.6	138.9	156.3	173.6	191.0	208.3	225.7	243.0	260.4	19
29					93.3	111.8	130.4	149.0	167.6	186.3	204.9	223.5	242.1	260.8	279.4	20
30						119.6	139.5	159.4	179.3	199.2	219.1	239.0	258.9	278.8	298.6	21
31						127.7	149.0	170.2	191.5	212.7	234.0	255.2	276.5	297.7	318.9	22
32						136.1	158.7	181.4	204.1	226.7	249.4	272.0	294.7	317.4	340.0	23
33						144.7	168.8	192.9	217.0	241.1	265.1	289.2	313.3	337.4	361.4	24
34						153.6	179.2	204.7	230.3	255.9	281.4	306.9	332.5	358.1	383.7	25
35							190.0	216.9	244.0	271.1	298.2	325.2	352.3	379.3	406.3	26
36							200.9	229.5	258.1	286.8	315.4	344.1	372.7	401.4	429.9	27
37							212.1	242.4	272.7	303.0	333.3	363.5	393.8	424.0	454.2	28
38							223.7	255.7	287.6	319.6	351.5	383.4	415.4	447.3	479.2	29
39							235.7	269.3	303.0	336.7	370.3	403.9	437.5	471.1	504.7	30
40								283.3	318.7	354.0	389.4	424.8	460.2	495.6	531.0	31
41								297.6	334.8	372.1	409.3	446.5	483.7	520.9	558.1	32
42								312.3	351.3	390.4	429.4	468.4	507.5	546.5	585.5	33
43								327.3	368.2	409.2	450.1	491.1	532.0	573.0	613.9	34
44								342.7	385.5	428.4	471.2	514.1	557.0	599.8	642.7	35
45									403.1	447.9	492.7	537.5	582.3	627.1	671.9	36
46									421.0	467.8	514.6	561.4	608.2	655.0	701.8	37
47									439.3	488.1	536.9	585.7	634.5	683.3	732.1	38
48									458.0	508.9	559.8	610.7	661.6	712.5	763.4	39
49									477.1	530.1	583.1	636.1	689.1	742.1	795.1	40
50									496.6	551.8	606.9	662.1	717.2	772.2	827.3	41
51									516.5	573.9	631.2	688.6	745.9	803.3	860.6	42
52									536.8	596.4	656.0	715.6	775.2	834.8	894.4	43
53									557.5	619.4	681.3	743.3	805.2	867.2	929.1	44
54									578.6	642.9	707.1	771.4	835.6	900.0	964.3	45
55									600.1	666.7	733.4	800.0	866.7	933.4	1000.0	46
56									622.0	691.1	760.2	829.2	898.3	967.3	1036.4	47
57									644.3	715.9	787.4	859.0	930.5	1002.1	1073.6	48
58									667.0	741.1	815.1	889.2	963.2	1037.3	1111.3	49
59									690.1	766.8	843.4	920.1	996.7	1073.4	1150.1	50
60									713.6	792.9	872.2	951.5	1030.8	1110.1	1189.4	51
61									737.5	819.4	901.3	983.3	1065.2	1147.2	1229.1	52
62									761.8	846.4	930.9	1015.5	1100.0	1184.5	1269.1	53
63									786.5	873.9	961.0	1048.2	1135.3	1222.4	1309.5	54
64									811.6	901.8	991.5	1081.3	1171.1	1260.9	1350.6	55
65									837.1	930.1	1022.5	1115.0	1207.9	1300.4	1393.2	56
66									863.0	958.9	1054.4	1149.9	1245.4	1340.9	1436.4	57
67									889.3	988.1	1086.8	1185.4	1284.0	1382.6	1481.2	58
68									916.0	1017.8	1119.6	1221.3	1323.1	1424.9	1526.6	59
69									943.1	1047.9	1152.7	1257.5	1362.3	1467.1	1572.0	60
70									970.6	1078.4	1186.3	1294.2	1402.0	1509.9	1617.7	61
71									998.5	1109.4	1220.3	1331.2	1442.1	1553.1	1664.0	62
72									1026.8	1140.9	1254.7	1368.6	1482.5	1596.4	1710.3	63
73									1055.5	1172.8	1289.5	1406.3	1523.2	1640.0	1756.9	64
74									1084.6	1205.1	1325.0	1445.4	1565.4	1685.8	1806.1	65
75									1114.1	1237.9	1361.0	1484.8	1608.0	1731.5	1855.3	66
76									1144.0	1271.1	1397.4	1524.5	1651.0	1777.6	1904.2	67
77									1174.3	1304.8	1434.2	1564.5	1694.3	1824.2	1954.0	68
78									1205.0	1338.9	1471.4	1605.2	1738.2	1871.2	2004.3	69
79									1236.1	1373.4	1509.1	1646.2	1782.5	1918.5	2055.2	70
80									1267.6	1408.4	1547.3	1687.5	1827.3	1967.4	2107.5	71
81									1299.5	1443.9	1586.2	1729.4	1872.6	2015.8	2159.4	72
82									1331.8	1479.8	1625.6	1772.6	1919.3	2066.5	2213.7	73
83									1364.5	1516.1	1665.4	1816.2	1966.5	2116.8	2268.5	74
84									1397.6	1552.9	1705.7	1860.4	2014.5	2168.6	2323.8	75
85									1431.1	1590.1	1746.5	1905.0	2063.0	2221.0	2379.5	76
86									1465.0	1627.8	1787.8	1950.1	2112.1	2274.1	2436.5	77
87									1499.3	1665.9	1829.6	1995.7	2161.7	2327.7	2493.8	78
88									1534.0	1704.4	1871.9	2041.8	2211.8	2381.8	2551.7	79
89									1569.1	1743.4	1914.6	2088.4	2262.3	2436.5	2610.4	80
90									1604.6	1782.9	1957.8	2135.5	2313.3	2491.7	2669.6	81
91									1640.5	1822.8	2001.5	2183.5	2365.0	2547.4	2729.4	82
92									1676.8	1863.1	2045.7	2231.9	2417.4	2603.6	2789.8	83
93									1713.5	1903.9	2090.4	2280.4	2470.3	2660.3	2850.3	84
94									1750.6	1945.1	2135.6	2329.4	2523.6	2717.5	2911.3	85
95									1788.1	1986.8	2181.2	2378.8	2577.4	2776.1	2974.7	86
96									1826.0	2028.9	2227.2	2428.6	2631.5	2834.3	3037.2	87
97									1864.3	2071.4	2273.6	2479.1	2686.0	2892.9	3099.7	88
98									1903.0	2114.4	2320.5	2530.1	2740.9	2951.8	3162.6	89
99									1942.1	2157.9	2368.1	2581.6	2796.4	3011.2	3226.0	90
100									1981.6	2201.8	2416.3	2633.5	2852.3	3071.1	3289.9	91
101									2021.5	2246.2	2465.1	2686.5	2909.4	3132.3	3355.3	92
102									2061.8	2291.0	2514.5	2740.1	2967.7	3195.3	3422.9	93
103									2102.5	2336.2	2564.5	2794.3	3026.5	3258.7	3490.9	94
104									2143.6	2381.8	2615.1	2849.1	3085.8	3322.4	3559.1	95
105									2185.1	2427.9	2666.3	2904.6	3145.5	3386.5	3627.4	96
106									2227.0	2474.4	2718.1	2960.7	3205.8	3451.4	3696.9	97
107									2269.3	2521.4	2770.4	3017.5	3266.5	3516.6	3766.6	98
108									2312.0	2568.9	2823.3	3074.8	3327.7	3582.2	3836.7	99
109									2355.1	2616.8	2876.8	3132.7	3389.3	3648.3	3907.3	100
110									2398.6	2665.2	2930.8	3191.2	3451.4	3714.8	3978.2	101
111									2442.5	2714.0	2985.4	3250.3	3514.0	3781.2	4049.5	102
112									2486.8	2763.2	3040.5	3310.0	3578.1	3850.1	4122.2	103
113									2531.5	2812.8	3095.2	3370.3	3643.0	3919.5	4196.1	104
114									2576.6	2862.9	3150.5	3431.2	3708.6	3989.4	4270.3	105
115									2622.1	2913.4	3206.3	3492.7	3774.8	4060.8	4346.9	106
116									2668.0	2964.4	3262.7	3554.8	3841.8	4128.9	4415.9	107
117									2714.3	3015.8	3319.6	3617.4	3909.3	4201.1	4493.0	108
118									2761.0	3067.7	3377.1	3680.6	3977.4	4274.2	4571.0	109
119									2808.1	3120.1	3435.1	3744.2	4046.2	4348.3	4650.3	110
120									2855.6	3173.0	3493.7	3808.4	4115.7	4423.1	4730.5	111
121									2903.5	3226.4	3552.8	3873.2	4185.7	4498.1	4810.6	112
122									2951.8	3280.2	3612.5	3938.5	4256.3	4574.1	4891.8	113
123									3000.5	3334.5	3672.7	4004.4	4327.4	4650.3	4973.2	114
124									3049.6	3389.3	3733.5	4070.8	4399.1	4727.4	5055.7	115
125									3099.1	3444.5	3794.8	4137.8	4471.4	4805.0	5138.6	116
126									3149.0	3500.2	3856.7	4205.3	4544.4	4883.5	5222.6	117
127									3199.3	3556.4	3919.1	4273.3	4618.0	4962.7	5307.4	118
128									3250.0	3613.1	3982.1	4341.9	4692.2	5042.5	5392.8	119
129									3301.1	3670.2	4045.6	4411.1	4767.0	5123.0	5479.0	120
130									3352.6	3727.8	4109.7	4480.8	4842.4	5204.1	5565.8	121
131									3404.5	3785.9	4174.3	4551.1	4918.4	5285.8	5653.2	122
132									3456.8	3844.4	4239.4	4622.0	4995.0	5368.1	5741.2	123
133									3509.5	3903.4	4305.1	4693.5	5072.2	5451.0	5829.8	124
134									3562.6	3962.9	4371.3	4765.6	5150.0	5534.4	5919.0	125
135									3616.1	4022.9	4438.0	4838.3	5228.4	5618.5	6008.7	126
136									3670.0	4083.3	4505.3	4911.6	5307.4	5703.2	6099.0	127
137									3724.3	4144.2	4573.1	4985.5	5387.0	5788.5	6190.0	128
138									3779.0	4205.6	4641.4	5060.0	5467.2	5874.4	6281.6	129
139									3834.1	4267.5	4710.3	5135.1	5548.0	5960.9	6373.8	130
140									3889.6	4329.8	4779.7	5210.8	5629.4	6048.0	6466.7	131
141									3945.5	4392.6	4849.6	5287.1	5711.5	6135.8	6560.2	132
142									4001.8	4455.9	4920.1	5364.0	5794.2	6224.3	6654.4	133
143									4058.5	4519.7	4991.1	5441.5	5877.5	6313.4	6749.3	134
144									4115.6	4584.0	5062.6	5519.6	5961.4	6403.2	6845.0	135
145									4173.1	4648.8	5134.7	5598.3	6046.0	6493.7	6941.4	136
146									4231.0	4714.1	5207.3	5677.6	6131.2	6584.8	7038.4	137
147									4289.3	4779.8	5280.4	5757.5	6217.1	6676.7	7136.3	138
148									4348.0	4846.1	5354.1	5838.0	6303.8	6769.5	7235.1	139
149									4407.2	4912.8	5428.3	5919.1	6391.3	6863.1	7334.8	140
150									4466.8	4980.0	5503.1	6000.8	6479.6	6957.4	7435.3	141
151									4526.8	5047.7	5578.4	6083.2	6568.7	7052.5	7536.7	142
152									4587.3	5115.9	5654.2	6166.2	6658.6	7148.4	7639.0	143
153									4648.2	5184.6	5730.6	6249.9	6749.3	7245.1	7742.3	144
154									4709.6	5253.8	5807.5	6334.3	6840.7	7342.6	7846.4	145
155									4771.4	5323.5	5885.0	6419.3	6932.9	7441.0	7951.4	146
156									4833.6	5393.7	5963.0	6505.0	7025.9	7540.3	8057.3	147
157									4896.3	5464.4	6041.5	6591.4	7119.8	7640.4	8164.2	148
158									4959.4	5535.6	6120.5	6678.5	7214.5	7741.4	8272.0	149
159									5022.9	5607.3	6200.1	6766.3	7309.9	7843.3	8380.8	150
160									5086.9	5679.5	6280.2	6854.8	7406.2	7946.2	8490.5	151
161									5151.3	5752.2	6360.8	6943.9	7503.3	8050.0	8601.2	152
162									5216.2	5825.4	6442.0	7033.7	7601.2	8154.7	8712.9	153
163									5281.5	5899.1	6523.7	7124.2	7699.9	8260.4	8825.7	154
164									5347.3	5973.3	6606.0	7215.3	7799.4	8366.9	8939.5	155
165									5413.5	6048.0	6688.8	7307.1	7899.7	8474.4	9054.2	156
166									5480.2	6123.2	6772.2	7399.6	8000.8	8582.8	9170.0	157
167									5547.3	6198.9	6856.1	7492.8	8102.8	8692.2	9286.8	158
168									5614.9	6275.1	6940.6	7586.8	8205.6	8802.5	9404.5	159
169									5682.9	6351.8	7025.6	7681.5	8309.3	8913.8	9523.2	160
170									5751.4	6429.0	7111.3	7776.9	8413.8	9026.0	9643.0	161
171									5820.3	6506.7	7197.5	7873.1	8519.2	9139.1	9763.8	162
172									5889.7	6584.9	7284.2	7970.0	8625.5	9253.1	9885.7	163
173									5959.5	6663.6	7371.5	8067.7	8732.7	9368.0	10008.6	164
174									6029.8	6742.8	7459.3	8166.1	8840.8	9483.8	10132.5	165
175									6100.6	6822.5	7547.7	8265.3	8949.8	9600.5	10257.4	166
176									6171.8	6902.7	7636.6	8365.2	9059.7	9718.2	10383.4	167
177									6243.5	6983.4	7726.1	8465.9	9170.5	9836.8	10510.4	168
178									6315.6	7064.6	7816.2	8567.3	9282.2	9956.4	10638.5	169
179									6388.2	7146.3	7906.8	8669.5	9394.8	10076.9	10767.7	170
180									6461.3	7228.5	7998.1	8772.4	9508.3	10198.4	10898.0	171
181									6534.8	7311.2	8089.9	8876.2	9622.7	10320.8	11029.4	172
182									6608.8	7394.4	8182.3	8980.7	9738.0	10444.2	11161.9	173
183									6683.2	7478.1	8275.3	9086.1	9854.3	10568.6	11295.5	174
184									6758.1	7562.3	8368.9	9192.3	9971.5	10694.0	11430.2	175
185									6833.5	7647.0	8463.1	9299.4	10089.6	10820.4	11566.1	176
186									6909.4	7732.2	8557.9	9407.3	10208.6	10947.8	11703.1	177
187									6985.7	7817.9	8653.3	9516.1	10328.6	11076.2	11841.2	178
188									7062.5	7904.1	8749.2	9625.7	10449.5	11205.6	11980.4	179
189									7139.8	7990.8	8845.7	9736.2	10571.3	11336.0	12120.7	180
190									7217.5	8078.0	8942.8	9847.6	10694.1	11467.4	12262.1	181
191									7295.7	8165.7	9040.5	9959.9	10817.8	11599.8	12404.6	182
192									7374.4	8253.9	9138.8	10073.1	10942.4	11733.2	12548.1	183
193									7453.5	8342.6	9237.7	10187.2	11068.0	11867.6	12692.7	184
194									7533.2	8431.8	9337.2	10302.2	11194.6	12003.0	12838.4	185
195									7613.3	8521.5	9437.3	10418.1	11322.1	12139.4	12985.1	186
196									7693.8	8611.7	9538.0	10534.9	11450.6	12276.8	13132.9	187
197									7774.8	8702.4	9639.3	10652.6	11580.0	12415.2	13281.8	188
198									7856.3	8793.6	9741.1	10771.2	11710.4	12554.6	13431.8	189
199									7938.3	8885.3	9843.5	10890.8	11841.7	12695.0	13582.8	190
200									8020.7	8977.5	9946.5	11011.3	11973.9	12836.4	13734.9	191
201									8103.6	9070.2	10050.1	11132.8	12107.1	12978.8	13888.0	192
202									8187.0	9163.4	10154.2	11255.2	12241.2	13122.2	14042.1	193
203									8270.9	9257.1	10258.9	11378.6	12376.2	13266.6	14197.3	194
204									8355.2	9351.3	10364.2	11502.9	12512.2	13411.0	14353.5	195
205									8440.0	9446.0	10470.1	11628.1	12649.1	13556.4	14510.7	196
206									8525.3	9541.2	10576.6	11754.3	12787.0	13702.8	14668.9	197
207									8611.0	9636.9	10683.7	11881.4	12925.8	13849.2	14827.1	198
208									8697.2	9733.1	10791.3	12009.5	13065.5	13996.6	14985.3	199
209									8783.8	9829.8	10899.5	12138.5	13206.2	14144.0	15143.5	200
210									8870.9	9927.0	11008.2	12268.5	13347.8	14291.4	15302.7	201
211									8958.5	10024.7	11117.4	12399.4	13490.4	14438.8	15462.9	202
212									9046.6	10122.9	11227.2	12531.3	13634.0	14587.2	15624.1	203
213									9135.1	10221.6	11337.5	12664.1	13778.6	14736.6	15786.3	204
214									9224.2	10320.8	11448.4	12797.8	13924.2	14886.0	15949.5	205
215									9313.7	10420.5	11559.8	12932.5	14070.8	15035.4	16113.7	206
216									9403.7	10520.7	11671.8	13068.1	14218.3	15184.8	16278.9	207
217									9494.2	10621.4	11784.3	13204.7	14366.8	15334.2	16444.1	208
218									9585.2	10722.6	11897.4	13342.2	14516.3	15483.6	16609.3	209
219									9676.7	10824.3	12011.0	13480.7	14666.8	15633.0	16774.5	210
220									9768.7	10926.5	12125.2	13620.2	14818.2	15782.4	16939.7	211
221									9861.2	11029.2	12240.0	13760.7	14970.7	15931.8	17104.9	212
222									9954.2	11132.4	12355.3	13902.2	15124.2	16081.2	17270.1	213
223									10047.7	11236.1	12471.2	14044.7	15278.7	16230.6	17435.3	214
224									10141.7	11340.3	12587.7	14188.2	15434.2	16380.0	17600.5	215
225									10236.2	11445.0	12704.7	14332.7	15590.7	16529.4	17765.7	216
226									10331.2	11550.2	12822.3	14478.2	15748.2	16678.8	17930.9	217
227									10426.7	11655.9	12940.4	14624.7	15906.7	16828.2	18096.1	218
228									10522.7	11762.1	13059.0	14772.2	16066.2	16977.6	18261.3	219
229									10619.2	11868.8	13178.2	14920.7	16226.7	17127.0	18426.5	220
230									10716.2	11976.0	13297.9	15070.2	16388.2	17276.4	18591.7	221
231									10813.7	12083.7	13418.1	15220.7	16550.7	17425.8	18756.9	222
232									10911.7	12191.9	13538.8	15372.2	16714.2	17575.2	18922.1	223
233									11010.2	12300.6	13660.0	15524.7	16878.7	17724.6	19087.3	224
234									11109.2	12409.8	13781.7	15678.2	17044.2	17874.0	19252.5	225
235									11208.7	12519.5	13903.9	15832.7	17210.7	18023.4	19417.7	226
236									11308.7	12629.7	14026.7	15988.2	17378.2	18172.8	19582.9	227
237									11409.2	12740.4	14150.0	16144.7	17546.7	18322.2

TOTAL STEM NET CUBIC FOOT VOLUME
YELLOW PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.2															0
2	.3	.4														0
3	.4	.6	.7													0
4	.5	.8	1.2	1.5												0
5	.7	1.2	1.7	2.2	2.7											0
6	.9	1.6	2.4	3.1	3.8	4.5										0
7	1.2	2.2	3.1	4.1	5.1	6.1	7.1									0
8	1.5	2.7	4.0	5.3	6.6	7.9	9.2	10.5								0
9	1.8	3.4	5.0	6.7	8.3	9.9	11.6	13.2	14.8							0
10		4.2	6.2	8.2	10.2	12.2	14.2	16.3	18.3							0
11		5.0	7.4	9.8	12.3	14.7	17.2	19.6	22.1	24.6						0
12		5.9	8.8	11.7	14.6	17.5	20.4	23.4	26.3	29.3						0
13		6.9	10.3	13.7	17.1	20.5	23.9	27.4	30.9	34.4	38.0					0
14		8.0	11.9	15.8	19.8	23.8	27.8	31.8	35.9	40.0	44.1					0
15			13.6	18.1	22.7	27.3	31.9	36.5	41.2	45.9	50.7	55.5				2
16			15.4	20.6	25.8	31.0	36.3	41.6	46.9	52.3	57.7	63.2				5
17			17.4	23.2	29.1	35.0	41.0	47.0	53.0	59.1	65.3	71.5	77.8			4
18			19.5	26.0	32.6	39.2	45.9	52.7	59.5	66.4	73.3	80.3	87.4			1
19			21.7	29.0	36.3	43.7	51.2	58.8	66.4	74.1	81.9	89.7	97.6	105.6		1
20				32.1	40.2	48.5	56.8	65.2	73.7	82.3	90.9	99.6	108.5	117.4		6
21				35.4	44.4	53.5	62.7	72.0	81.4	90.8	100.4	110.1	119.9	129.8	139.8	4
22				38.8	48.7	58.7	68.9	79.1	89.4	99.9	110.5	121.2	132.0	142.9	153.9	4
23				42.4	53.3	64.2	75.3	86.6	97.9	109.4	121.0	132.8	144.6	156.6	168.8	5
24				46.2	58.0	70.0	82.1	94.4	106.8	119.4	132.1	144.9	157.9	171.1	184.4	3
25					63.0	76.0	89.2	102.6	116.1	129.8	143.6	157.7	171.9	186.3	200.8	4
26					68.2	82.3	96.6	111.1	125.8	140.7	155.7	171.0	186.5	202.1	218.0	5
27					73.5	88.8	104.3	120.0	135.9	152.0	168.4	184.9	201.7	218.7	236.0	3
28					79.1	95.6	112.3	129.2	146.4	163.8	181.5	199.4	217.6	236.0	254.7	1
29					84.9	102.7	120.6	138.9	157.4	176.1	195.2	214.5	234.2	254.1	274.3	1
30						110.0	129.3	148.9	168.7	188.9	209.4	230.3	251.4	272.8	294.6	0
31						117.6	138.2	159.2	180.5	202.2	224.2	246.6	269.3	292.4	315.8	0
32						125.4	147.5	169.9	192.8	216.0	239.6	263.5	287.9	312.7	337.8	0
33						133.5	157.1	181.1	205.4	230.2	255.4	281.1	307.2	333.7	360.7	0
34						141.9	167.0	192.5	218.5	245.0	271.9	299.3	327.2	355.5	383.7	0
35							177.2	204.4	232.1	260.2	288.9	318.1	347.9	378.2	406.6	0
36							187.8	216.7	246.1	276.0	306.5	337.6	369.3	401.4	430.1	0
37							198.7	229.3	260.5	292.3	324.7	357.8	391.5	424.0	454.3	0
38							209.9	242.3	275.4	309.1	343.5	378.6	414.3	447.3	479.2	0
39							221.5	255.7	290.7	326.4	362.8	400.0	437.5	471.1	504.7	0
40								269.5	306.5	344.3	382.8	422.2	460.2	495.6	530.9	0
41								283.7	322.8	362.6	403.4	445.0	483.5	520.6	557.8	0
42								298.4	339.5	381.5	424.5	468.3	507.3	546.3	585.3	0
43								313.4	356.7	401.0	446.3	490.9	531.8	572.6	613.5	0
44								328.8	374.3	421.0	468.7	513.9	556.8	599.6	642.4	0
45									392.5	441.5	491.7	537.6	582.3	627.1	671.9	0
46									411.1	462.6	514.9	561.7	608.5	655.3	702.1	0
47									430.2	484.3	537.5	586.4	635.2	684.1	732.9	0
48									449.8	506.5	560.7	611.6	662.5	713.5	764.4	0
49									469.9	529.3	584.2	637.3	690.4	743.5	796.6	0
50									490.5	552.6	608.3	663.6	718.9	774.2	829.4	0

DBH CLASS	HEIGHT CLASS															BASIC TREES
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
1	.2															1
2	.3	.4														0
3	.4	.6	.8													0
4	.5	.9	1.2	1.5												0
5	.7	1.2	1.7	2.3	2.8											0
6	.9	1.7	2.4	3.2	3.9	4.6										0
7	1.2	2.2	3.2	4.2	5.2	6.2	7.2									1
8	1.5	2.8	4.1	5.4	6.8	8.1	9.4	10.7								1
9	1.9	3.5	5.2	6.8	8.5	10.2	11.8	13.5	15.2							2
10		4.3	6.3	8.4	10.4	12.5	14.6	16.7	18.8							1
11		5.1	7.6	10.1	12.6	15.1	17.6	20.1	22.7	25.2						1
12		6.1	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0						1
13		7.1	10.6	14.0	17.5	21.1	24.6	28.1	31.7	35.2	38.7					4
14		8.2	12.2	16.3	20.3	24.4	28.5	32.6	36.8	40.9	45.1					2
15			14.0	18.7	23.3	28.0	32.7	37.5	42.2	47.0	51.8	56.6				1
16			15.9	21.3	26.5	31.9	37.2	42.6	48.1	53.5	59.0	64.6				3
17			17.9	23.9	29.9	36.0	42.1	48.2	54.3	60.5	66.7	73.0	79.4			2
18			20.1	26.8	33.6	40.3	47.2	54.0	61.0	67.9	74.9	82.0	89.2			7
19			22.4	29.9	37.4	45.0	52.6	60.3	68.0	75.8	83.6	91.5	99.5	107.6		17
20				33.1	41.4	49.8	58.2	66.8	75.4	84.1	92.8	101.5	110.4	119.3		5
21				36.6	45.7	55.0	64.3	73.8	83.3	92.8	102.4	112.1	121.9	131.8	141.7	10
22				40.3	50.4	60.4	70.7	81.0	91.5	102.0	112.6	123.4	134.1	144.9	155.9	11
23				44.2	54.8	65.5	77.3	88.7	100.1	111.7	123.3	135.1	146.9	158.8	170.8	
24				47.4	59.7	71.9	84.2	96.6	109.0	121.8	134.6	147.5	160.4	173.4	186.4	1
25					64.9	78.1	91.5	105.0	118.6	132.3	146.2	160.2	174.2	188.5	202.8	1
26					70.3	84.4	99.1	113.7	128.5	143.4	158.4	173.6	188.9	204.2	219.9	1
27					75.7	91.3	106.9	122.7	138.7	154.8	171.1	187.5	204.1	220.9	237.8	1
28					81.5	98.2	115.1	132.2	149.4	166.8	184.3	202.1	220.1	238.1	256.4	
29					87.5	105.4	123.6	142.4	160.4	179.3	198.2	217.2	236.5	256.0	275.8	
30						112.9	132.4	152.1	172.0	192.1	212.4	232.9	253.7	274.7	295.9	
31						120.7	141.5	162.6	183.9	205.4	227.1	249.0	271.2	293.6	316.3	
32						128.7	151.0	173.5	196.2	219.2	242.4	265.8	289.4	313.3	337.5	
33						137.0	160.7	184.7	209.0	233.5	258.3	283.4	308.8	334.5	360.4	
34						145.5	170.6	196.3	222.2	248.4	274.8	301.5	328.5	355.8	383.4	
35							180.7	208.3	235.8	263.7	291.8	320.2	348.9	378.0	407.4	
36							191.0	220.4	249.4	279.0	309.0	339.3	369.8	400.6	431.8	
37							201.6	232.6	263.3	294.6	326.6	358.8	391.3	424.0	457.1	
38							212.4	245.0	277.4	310.5	344.2	378.4	412.6	447.1	482.0	
39							223.4	257.7	291.8	326.7	362.2	398.2	434.2	470.4	507.2	
40							234.7	270.7	306.6	343.3	380.6	418.4	456.2	494.2	532.8	
41							246.2	284.0	321.6	360.1	399.3	438.9	478.5	518.5	559.0	
42							258.0	297.5	337.0	377.3	418.5	460.0	501.5	543.4	585.7	
43							270.1	311.3	352.6	394.8	437.9	481.3	524.7	568.5	612.7	
44							282.4	325.4	368.5	412.6	457.6	503.0	548.3	594.0	640.0	
45							294.9	339.8	384.8	430.8	477.8	525.2	572.3	619.9	667.8	
46							307.7	354.5	401.4	449.4	498.4	547.8	597.0	646.3	696.1	
47							320.7	369.5	418.4	468.4	519.5	571.0	622.2	673.8	725.8	
48							334.0	384.7	435.6	487.8	540.9	594.6	647.9	701.7	755.9	
49							347.5	400.3	453.3	507.5	562.8	618.6	674.1	730.1	786.4	
50							361.3	416.2	471.3	527.6	585.1	643.1	700.7	758.9	817.4	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNFORKED TREES
YELLOW PINE
SANTA FE-CARSON-LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.5	1.0	1.4	1.9	2.4											0
6	.7	1.5	2.2	2.9	3.6	4.3										0
7	1.0	2.0	3.0	4.0	5.0	6.0	7.1									1
8	1.2	2.6	4.0	5.3	6.7	8.0	9.4	10.7								1
9	1.5	3.3	5.0	6.7	8.5	10.2	12.0	13.7	15.4							0
10		4.0	6.2	8.4	10.5	12.7	14.8	17.0	19.2							3
11		4.9	7.5	10.1	12.8	15.4	18.0	20.6	23.3	25.9						1
12		5.8	8.9	12.1	15.2	18.3	21.5	24.6	27.8	30.9						1
13		6.8	10.5	14.2	17.9	21.6	25.3	28.9	32.6	36.3	40.0					4
14		7.8	12.1	16.4	20.7	25.0	29.3	33.6	37.9	42.2	46.5					3
15			13.9	18.8	23.8	28.7	33.7	38.6	43.6	48.5	53.4	58.4				3
16			15.8	21.4	27.1	32.7	38.3	44.0	49.6	55.2	60.8	66.5				7
17			17.8	24.2	30.6	36.9	43.3	49.6	56.0	62.4	68.7	75.1	81.4			11
18			20.0	27.1	34.3	41.4	48.5	55.7	62.8	69.9	77.1	84.2	91.4			7
19			22.3	30.2	38.2	46.1	54.1	62.0	70.0	78.0	85.9	93.9	101.8	109.8		16
20				33.5	42.3	51.1	59.9	68.8	77.6	86.4	95.2	104.0	112.9	121.7		10
21				36.9	46.6	56.4	66.1	75.8	85.5	95.3	105.0	114.7	124.4	134.2	143.9	14
22				40.5	51.2	61.8	72.5	83.2	93.9	104.6	115.2	125.9	136.6	147.3	158.0	15
23				44.2	55.9	67.6	79.3	90.9	102.6	114.3	126.0	137.7	149.3	161.0	172.7	9
24				48.2	60.9	73.6	86.3	99.0	111.7	124.5	137.2	149.9	162.6	175.3	188.0	17
25					66.1	79.9	93.7	107.5	121.3	135.1	148.9	162.7	176.5	190.3	204.1	15
26					71.4	86.4	101.3	116.2	131.2	146.1	161.0	175.9	190.9	205.8	220.7	14
27					77.0	93.1	109.2	125.3	141.4	157.5	173.6	189.7	205.8	221.9	238.1	14
28					82.8	100.2	117.5	134.8	152.1	169.4	186.8	204.1	221.4	238.7	256.0	8
29					88.9	107.4	126.0	144.6	163.2	181.8	200.3	218.9	237.5	256.1	274.7	9
30						115.0	134.9	154.7	174.6	194.5	214.4	234.3	254.2	274.0	293.9	8
31						122.8	144.0	165.2	186.5	207.7	228.9	250.2	271.4	292.6	313.9	6
32						130.8	153.4	176.1	198.7	221.3	243.9	266.6	289.2	311.8	334.5	2
33						139.1	163.2	187.2	211.3	235.4	259.4	283.5	307.6	331.6	355.7	1
34						147.7	173.2	198.8	224.3	249.8	275.4	300.9	326.5	352.0	377.6	2
35							183.5	210.6	237.7	264.8	291.8	318.9	346.0	373.1	400.1	0
36							194.2	222.8	251.5	280.1	308.7	337.4	366.0	394.7	423.3	0
37							205.1	235.4	265.6	295.9	326.1	356.4	386.7	416.9	447.2	0
38							216.3	248.3	280.2	312.1	344.0	375.9	407.8	439.8	471.7	0
39							227.9	261.5	295.1	328.7	362.3	396.0	429.6	463.2	496.8	0
40								275.1	310.4	345.8	381.2	416.5	451.9	487.3	522.6	0
41								289.0	326.1	363.3	400.5	437.6	474.8	511.9	549.1	0
42								303.3	342.2	381.2	420.2	459.2	498.2	537.2	576.2	0
43								317.9	358.7	399.6	440.5	481.4	522.2	563.1	604.0	0
44								332.8	375.6	418.4	461.2	504.0	546.8	589.6	632.4	0
45									392.9	437.6	482.4	527.2	571.9	616.7	661.5	0
46									410.5	457.3	504.1	550.9	597.6	644.4	691.2	0
47									428.6	477.4	526.2	575.1	623.9	672.7	721.6	0
48									447.0	497.9	548.9	599.8	650.7	701.7	752.6	0
49									465.8	518.9	572.0	625.1	678.1	731.2	784.3	0
50									485.0	540.3	595.6	650.8	706.1	761.4	816.6	0

BASIS

DBH CLASS	HEIGHT CLASS															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASAL TOTAL
5	.5	.9	1.3	1.7	2.1											
6	.7	1.3	1.9	2.6	3.2	3.8										
7	.9	1.8	2.7	3.6	4.5	5.4	6.4									
8	1.1	2.3	3.5	4.8	6.0	7.2	8.4	9.7								
9	1.4	2.9	4.5	6.1	7.6	9.2	10.8	12.4	14.0							
10		3.6	5.5	7.5	9.5	11.4	13.4	15.4	17.4							
11		4.3	6.7	9.1	11.5	13.9	16.2	18.7	21.1	23.5						
12		5.2	8.0	10.8	13.7	16.5	19.4	22.3	25.3	28.2						
13		6.0	9.4	12.7	16.1	19.5	22.9	26.3	29.7	33.2	36.7					
14		7.0	10.8	14.7	18.7	22.6	26.6	30.6	34.6	38.6	42.7					
15			12.4	16.9	21.4	26.0	30.6	35.2	39.8	44.5	49.2	54.0				
16			14.1	19.2	24.4	29.6	34.8	40.1	45.4	50.8	56.1	61.6				
17			16.0	21.7	27.6	33.4	39.4	45.3	51.4	57.4	63.6	69.7	76.			
18			17.9	24.4	30.9	37.5	44.2	50.9	57.7	64.5	71.4	78.4	85.4			
19			19.9	27.2	34.5	41.8	49.3	56.8	64.4	72.1	79.8	87.6	95.4	103.		
20				30.1	38.2	46.4	54.7	63.1	71.5	80.0	88.7	97.4	106.2	115.1		
21				33.2	42.0	51.0	60.4	69.6	79.0	88.5	98.2	107.9	117.8	127.8	137.9	
22				36.4	46.3	56.3	66.4	76.6	86.9	97.3	107.8	118.5	129.2	140.	151.0	
23				39.8	50.6	61.6	72.6	83.8	95.1	106.4	118.2	129.9	141.8	153.8	165.9	
24				43.4	55.2	67.1	79.2	91.4	103.8	116.2	129.0	141.9	154.9	168.	181.4	
25					59.9	72.9	86.0	99.4	113.0	126.5	140.4	154.4	168.6	183.	197.6	
26					64.8	78.8	93.0	107.7	122.6	137.3	152.3	167.5	183.	198.	214.	
27					70.0	85.1	100.6	116.3	132.2	148.1	164.4	181.0	198.	214.	231.	
28					75.3	91.7	108.4	125.3	142.4	159.6	177.0	195.0	213.	231.	249.	
29					80.9	98.5	116.4	134.6	153.1	171.6	190.4	210.	229.	249.	269.	
30						105.5	124.8	144.4	164.2	184.4	204.9	225.7	246.9	268.	289.	
31						112.8	133.5	154.4	175.7	197.2	219.0	241.0	263.5	286.	309.	
32						120.4	142.4	164.9	187.7	211.0	234.5	258.	282.	306.	331.	
33						128.2	151.7	175.7	200.0	224.8	250.0	275.4	301.2	327.	353.	
34						136.2	161.3	186.8	212.8	239.2	266.0	293.1	320.6	348.	376.	
35							171.2	198.4	226.0	254.1	282.9	312.1	341.6	371.	401.	
36							181.4	210.3	239.7	269.5	300.1	331.1	362.4	394.	426.	
37							192.1	222.6	253.8	285.4	318.1	351.1	384.2	418.	452.	
38							202.8	235.0	268.0	301.4	336.2	371.2	406.1	442.	478.	
39							214.0	248.3	283.0	318.4	355.2	392.2	429.0	467.	505.	
40								261.7	298.4	335.7	374.6	413.5	452.6	493.	533.	
41								275.6	314.1	353.5	394.4	435.4	476.6	519.	561.	
42								289.8	330.1	371.4	414.4	457.5	500.8	545.	589.	
43								304.4	346.7	390.0	435.0	480.2	525.7	572.	618.	
44								319.4	363.8	409.2	456.5	503.9	551.6	600.	648.	
45									381.2	428.8	478.4	528.0	577.9	628.	679.	
46									398.9	448.8	500.7	552.5	604.8	658.	711.	
47									417.0	469.2	523.4	577.5	632.1	687.	743.	
48									435.4	489.9	546.4	603.0	660.0	718.	776.	
49									454.2	511.0	570.0	628.9	688.3	749.	810.	
50									473.5	532.6	594.1	655.5	717.4	780.	844.	

NET CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES
YELLOW PINE
LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.5	.9	1.3	1.7	2.2											0
6	.7	1.3	2.0	2.7	3.3	4.0										0
7	.9	1.8	2.8	3.7	4.6	5.6	6.5									0
8	1.1	2.4	3.6	4.9	6.1	7.4	8.7	9.9								1
9	1.4	3.0	4.6	6.2	7.8	9.4	11.1	12.7	14.3							0
10		3.7	5.7	7.7	9.7	11.7	13.8	15.8	17.8							1
11		4.5	6.9	9.3	11.8	14.2	16.7	19.2	21.7	24.2						1
12		5.3	8.2	11.1	14.1	17.0	20.0	22.9	25.9	28.9						1
13		6.2	9.6	13.1	16.5	20.0	23.5	27.0	30.5	34.0	37.6					4
14		7.2	11.2	15.2	19.2	23.2	27.3	31.4	35.5	39.6	43.7					0
15			12.8	17.4	22.1	26.7	31.4	36.1	40.8	45.6	50.3	55.1				1
16			14.6	19.8	25.1	30.4	35.8	41.1	46.5	52.0	57.4	62.9				6
17			16.5	22.4	28.4	34.4	40.4	46.5	52.6	58.8	65.0	71.2	77.5			9
18			18.5	25.1	31.8	38.6	45.4	52.2	59.1	66.0	73.0	80.0	87.1			7
19			20.6	28.0	35.5	43.0	50.6	58.3	66.0	73.7	81.5	89.4	97.3	105.2		17
20				31.0	39.4	47.7	56.2	64.7	73.2	81.8	90.5	99.3	108.1	116.9		9
21				34.2	43.4	52.7	62.0	71.4	80.9	90.4	100.0	109.7	119.4	129.3	139.2	12
22				37.6	47.7	57.9	68.1	78.5	88.9	99.4	110.0	120.6	131.4	142.2	153.2	12
23				41.1	52.2	63.3	74.6	85.9	97.3	108.8	120.4	132.2	144.0	155.9	167.9	9
24				44.8	56.8	69.0	81.3	93.6	106.1	118.7	131.4	144.2	157.1	170.2	183.3	14
25					61.7	74.9	88.3	101.7	115.3	129.0	142.9	156.8	170.9	185.1	199.5	12
26					66.8	81.1	95.6	110.2	124.9	139.8	154.8	170.0	185.3	200.8	216.4	10
27					72.1	87.6	103.2	119.0	135.0	151.1	167.3	183.7	200.3	217.1	234.0	13
28					77.6	94.3	111.1	128.2	145.4	162.7	180.3	198.0	216.0	234.1	252.4	9
29					83.3	101.2	119.3	137.7	156.2	174.9	193.8	212.9	232.2	251.7	271.5	9
30						108.4	127.9	147.5	167.4	187.5	207.8	228.3	249.1	270.1	291.4	9
31						115.9	136.7	157.7	179.0	200.6	222.3	244.4	266.6	289.2	312.0	8
32						123.6	145.8	168.3	191.1	214.1	237.4	261.0	284.8	309.0	333.4	2
33						131.6	155.3	179.3	203.5	228.1	253.0	278.2	303.6	329.4	355.6	2
34						139.8	165.0	190.5	216.4	242.6	269.1	295.9	323.1	350.7	377.6	2
35							175.1	202.2	229.7	257.5	285.7	314.3	343.2	372.6	400.1	0
36							185.5	214.2	243.4	272.9	302.9	333.3	364.0	394.7	423.3	0
37							196.1	226.6	257.5	288.9	320.6	352.8	385.5	416.9	447.2	0
38							207.1	239.4	272.1	305.2	338.9	373.0	407.6	439.8	471.7	0
39							218.4	252.5	287.1	322.1	357.7	393.8	429.6	463.2	496.8	0
40								266.0	302.5	339.5	377.1	415.2	451.9	487.3	522.6	0
41								279.9	318.3	357.3	397.0	437.2	474.8	511.9	549.1	0
42								294.1	334.6	375.7	417.4	459.2	498.2	537.2	576.2	0
43								308.7	351.3	394.5	438.5	481.4	522.2	563.1	604.0	0
44								323.7	368.4	413.9	460.1	504.0	546.8	589.6	632.4	0
45									386.0	433.7	482.3	527.2	571.9	616.7	661.5	0
46									404.0	454.1	504.1	550.9	597.6	644.4	691.2	0
47									422.5	474.9	526.2	575.1	623.9	672.7	721.6	0
48									441.4	496.3	548.9	599.8	650.7	701.7	752.6	0
49									460.8	518.2	572.0	625.1	678.1	731.2	784.3	0
50									480.6	540.3	595.6	650.8	706.1	761.4	816.6	0
BASIS																

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES-UNFORKED TREES
YELLOW PINE
SANTA FE-CARSON-LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.8	1.7	2.5	3.3	4.2	5.0	5.9									0
8	1.1	2.3	3.5	4.7	5.9	7.1	8.3	9.5								1
9	1.4	3.0	4.6	6.2	7.8	9.4	11.0	12.6	14.2							0
10		3.8	5.8	7.9	9.9	12.0	14.0	16.0	18.1							3
11		4.6	7.2	9.7	12.2	14.7	17.3	19.8	22.3	24.8						1
12		5.6	8.6	11.7	14.7	17.7	20.8	23.8	26.9	29.9						1
13		6.6	10.2	13.8	17.4	21.0	24.6	28.2	31.8	35.4	39.0					4
14		7.7	11.9	16.1	20.3	24.5	28.7	32.9	37.1	41.4	45.6					3
15			13.7	18.5	23.4	28.3	33.1	38.0	42.8	47.7	52.6	57.4				2
16			15.6	21.1	26.7	32.3	37.8	43.4	48.9	54.5	60.0	65.6				7
17			17.6	23.9	30.2	36.5	42.8	49.1	55.4	61.7	68.0	74.3	80.5			11
18			19.8	26.9	33.9	41.0	48.1	55.1	62.2	69.3	76.3	83.4	90.5			7
19			22.1	30.0	37.9	45.8	53.6	61.5	69.4	77.3	85.2	93.1	101.0	108.4		14
20				33.2	42.0	50.8	59.5	68.3	77.0	85.8	94.6	103.3	112.1	120.8		10
21				36.7	46.3	56.0	65.7	75.4	85.0	94.7	104.4	114.0	123.7	133.4	143.1	14
22				40.3	50.9	61.5	72.1	82.8	93.4	104.0	114.6	125.3	135.9	146.5	157.1	15
23				44.0	55.7	67.3	78.9	90.5	102.2	113.8	125.4	137.1	148.6	160.2	171.9	9
24				48.0	60.6	73.3	86.0	98.6	111.3	124.0	136.6	149.3	162.0	174.6	187.3	17
25					65.8	79.6	93.3	107.1	120.8	134.6	148.3	162.1	175.8	189.6	203.3	11
26					71.2	86.1	101.0	115.9	130.7	145.6	160.5	175.4	190.2	205.1	219.9	14
27					76.8	92.9	108.9	125.0	141.0	157.1	173.2	189.3	205.4	221.4	237.5	11
28					82.6	99.9	117.2	134.5	151.7	169.0	186.3	203.6	220.8	238.1	255.4	7
29					88.7	107.2	125.7	144.2	162.8	181.4	199.9	218.4	236.9	255.5	274.1	4
30						114.7	134.6	154.4	174.3	194.1	214.0	233.8	253.6	273.5	293.3	3
31						122.5	143.7	164.9	186.1	207.3	228.5	249.7	270.9	292.1	313.3	1
32						130.6	153.2	175.8	198.4	221.0	243.5	266.1	288.7	311.3	333.9	2
33						138.9	162.9	186.9	211.0	234.9	258.9	282.9	306.9	330.9	354.9	1
34						147.4	172.9	198.5	224.0	249.5	275.1	300.6	326.2	351.7	377.3	1
35							183.3	210.4	237.4	264.4	291.4	318.4	345.4	372.4	399.4	2
36							193.9	222.6	251.2	279.8	308.4	337.0	365.6	394.2	422.8	2
37							204.9	235.1	265.3	295.6	325.8	356.0	386.2	416.4	446.6	1
38							216.1	248.0	279.9	311.8	343.7	375.6	407.5	439.4	471.3	1
39							227.7	261.2	294.8	328.4	362.0	395.6	429.2	462.8	496.4	1
40								274.8	310.0	345.5	381.0	416.5	452.0	487.5	523.0	1
41								288.8	325.9	363.1	400.2	437.4	474.5	511.7	548.8	2
42								303.1	342.1	381.1	420.1	459.1	498.1	537.1	576.1	1
43								317.6	358.5	399.4	440.3	481.2	522.1	563.0	603.9	1
44								332.6	375.6	418.6	461.5	504.5	547.5	590.5	633.5	1
45									392.8	437.8	482.7	527.7	572.7	617.7	662.7	1
46									410.3	457.3	504.3	551.3	598.3	645.3	692.3	1
47									428.1	477.1	526.1	575.1	624.1	673.1	722.1	1
48									446.2	497.2	548.2	599.2	650.2	701.2	752.2	1
49									464.5	518.0	571.5	625.0	678.5	732.0	785.5	1
50									483.0	539.0	595.0	651.0	707.0	763.0	819.0	1

NET CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES
YELLOW PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.7	1.5	2.2	3.0	3.7	4.5	5.3									
8	1.0	2.1	3.1	4.2	5.3	6.4	7.5	8.6								
9	1.3	2.7	4.1	5.6	7.0	8.5	9.9	11.4	12.9							0
10		3.4	5.2	7.1	8.9	10.8	12.6	14.5	16.4							2
11		4.1	6.4	8.7	11.0	13.3	15.6	17.9	20.2	22.6						5
12		5.0	7.7	10.4	13.2	16.0	18.8	21.6	24.4	27.3						4
13		5.9	9.1	12.4	15.6	18.9	22.3	25.6	29.0	32.4	35.8					5
14		6.8	10.6	14.4	18.3	22.1	26.0	29.9	33.9	37.8	41.8					5
15			12.2	16.6	21.1	25.5	30.0	34.6	39.1	43.7	48.4	[illegible]				5
16			13.9	19.0	24.0	29.2	34.3	39.5	44.8	50.0	55.4	[illegible]				4
17			15.7	21.5	27.2	33.0	38.9	44.8	50.7	56.8	62.8	68.9	75.1			4
18			17.7	24.1	30.6	37.1	43.7	50.4	57.1	63.9	70.7	77.7	84.8			1
19			19.7	26.9	34.2	41.5	48.9	56.3	63.9	71.5	79.1	86.9	94.7	102.6		1
20				29.8	37.9	46.1	54.3	62.6	71.0	79.5	88.0	96.7	105.4	114.3		4
21				32.9	41.9	50.9	60.0	69.2	78.5	87.9	97.4	107.0	116.7	126.5	136.4	4
22				36.2	46.0	55.9	66.0	76.1	86.4	96.8	107.3	117.9	128.6	139.5	150.5	2
23				39.6	50.4	61.2	72.2	83.4	94.7	106.1	117.6	129.3	141.1	153.1	165.2	5
24				43.2	54.9	66.8	78.8	91.0	103.4	115.8	128.5	141.3	154.3	167.4	180.7	2
25					59.6	72.6	85.7	99.0	112.4	126.1	139.9	153.9	168.0	182.4	197.0	4
26					64.6	78.6	92.9	107.3	121.9	136.7	151.8	167.0	182.4	198.1	214.0	5
27					69.7	84.9	100.3	115.9	131.8	147.9	164.2	180.7	197.5	214.5	231.8	3
28					75.1	91.4	108.1	124.9	142.1	159.5	177.1	195.0	213.2	231.6	250.3	1
29					80.6	98.2	116.1	134.3	152.8	171.5	190.6	209.9	229.5	249.4	269.7	1
30						105.3	124.5	144.0	163.9	184.1	204.5	225.4	246.5	268.0	289.9	0
31						112.6	133.2	154.1	175.4	197.1	219.1	241.5	264.2	287.3	310.9	0
32						120.1	142.2	164.5	187.4	210.6	234.2	258.2	282.6	307.4	332.7	0
33						127.9	151.4	175.4	199.7	224.5	249.8	275.5	301.6	328.3	355.1	0
34						136.0	161.1	186.6	212.5	239.0	266.0	293.4	321.4	349.9	377.1	0
35							171.0	198.1	225.8	254.0	282.7	312.0	341.9	372.3	393.6	0
36							181.2	210.0	239.5	269.4	300.0	331.2	363.0	394.2	422.8	0
37							191.8	222.4	253.6	285.4	317.9	351.1	384.9	416.5	446.7	0
38							202.6	235.0	268.1	301.9	336.4	371.6	407.4	439.3	471.2	0
39							213.8	248.1	283.1	318.9	355.5	392.8	429.2	462.8	496.4	0
40								261.6	298.6	336.4	375.1	414.6	451.5	486.8	522.2	0
41								275.4	314.5	354.5	395.3	437.2	474.4	511.5	548.7	0
42								289.6	330.8	373.0	416.2	458.9	497.9	536.8	575.8	0
43								304.3	347.7	392.1	437.7	481.0	521.9	562.7	603.6	0
44								319.3	365.0	411.8	459.7	503.7	546.5	589.2	632.0	0
45									382.7	432.0	482.1	526.9	571.6	616.3	661.1	0
46									401.0	452.7	503.8	550.6	597.3	644.1	690.8	0
47									419.7	474.0	526.0	574.8	623.6	672.4	721.2	0
48									438.9	495.8	548.6	599.5	650.4	701.3	752.2	0
49									458.5	518.2	571.7	624.8	677.8	730.9	783.9	0
50									478.7	540.0	595.3	650.5	705.8	761.0	816.3	0
BASIS TREES	0	0	2	2	8	11	9	10	5	4	2	0	0	0	0	

YELLOW PINE
LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS														
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
7	.7	1.5	2.3	3.1	3.8	4.6	5.4								
8	1.0	2.1	3.2	4.3	5.4	6.5	7.7	8.8							
9	1.3	2.8	4.2	5.7	7.2	8.7	10.2	11.7	13.2						
10		3.5	5.4	7.3	9.2	11.1	13.0	14.9	16.8						
11		4.3	6.6	8.9	11.3	13.6	16.	18.4	20.8	23.1					
12		5.1	7.9	10.8	13.6	16.4	19.2	22.1	25.1	27.9					
13		6.0	9.4	12.7	16.1	19.5	22.9	26.3	29.7	33.1	36.5				
14		7.0	10.9	14.8	18.8	22.7	26.7	30.7	34.7	38.6	42.6				
15			12.6	17.1	21.7	26.2	30.8	35.3	39.9	44.4	49.				
16			14.4	19.5	24.8	30.1	35.4	40.7	45.9	51.2	56.5				
17			16.3	22.1	28.	34.	39.9	45.8	51.7	57.6	63.				
18			18.3	24.9	31.6	38.	44.9	51.7	58.6	65.4	72.1	78.			
19			20.4	27.8	35.	42.	49.9	57.8	65.6	73.4	81.1	88.			
20				30.8	39.	47.	55.8	64.	72.	81.7	90.3	98.			
21				34.0	43.1	52.	61.8	70.	79.	88.8	98.3	107.			
22				37.4	47.4	57.3	67.4	77.4	87.3	97.3	107.2	117.			
23				41.0	52.	62.9	73.9	84.8	95.8	106.7	117.6	128.			
24				44.8	56.8	68.7	80.6	92.6	104.5	116.4	128.3	140.			
25					61.9	74.8	87.8	100.7	113.7	126.7	139.6	152.			
26					67.2	81.2	95.3	109.3	123.4	137.4	151.5	165.			
27					72.7	87.9	103.1	118.3	133.5	148.7	163.9	179.			
28					78.4	94.8	111.2	127.6	144.0	160.4	176.8	193.			
29					84.3	101.9	119.6	137.2	154.9	172.5	190.1	207.			
30					90.4	109.3	128.2	147.1	166.1	185.0	203.9	223.			
31						116.9	137.1	157.3	177.6	197.8	218.0	238.			
32						124.7	146.3	167.8	189.4	211.0	232.5	254.			
33						132.7	155.7	178.6	201.6	224.6	247.5	270.			
34						140.9	165.3	189.7	214.1	238.5	262.9	287.			
35						149.3	175.2	201.0	226.9	252.8	278.7	304.			
36						157.9	185.3	212.6	240.0	267.4	294.7	322.			
37						166.7	195.6	224.5	253.4	282.3	311.2	340.			
38						175.7	206.2	236.6	267.1	297.5	327.9	358.			
39						184.9	217.0	249.0	281.1	313.1	345.1	377.			
40						194.3	228.0	261.7	295.4	329.1	362.8	396.			
41						203.9	239.3	274.6	310.0	345.3	380.7	416.			
42						213.7	250.8	287.8	324.9	361.9	398.9	436.			
43						223.7	262.5	301.3	340.1	378.9	417.7	456.			
44						233.9	274.5	315.0	355.6	396.1	436.7	477.			
45						244.3	286.8	329.2	371.7	414.1	456.5	499.			
46						254.9	299.3	343.7	388.1	432.4	476.8	521.			
47						265.7	312.0	358.3	404.6	450.9	497.2	543.			
48						276.7	325.0	373.3	421.6	469.9	518.2	566.			
49						287.9	338.2	388.5	438.8	489.1	539.4	589.			
50						299.3	351.6	403.9	456.2	508.5	560.8	613.			
51							365.3	419.6	473.9	528.2	582.5	637.			
52							379.2	435.6	492.0	548.4	604.8	661.			
53							393.4	451.9	510.4	568.9	627.4	686.			
54							407.8	468.4	529.0	589.6	650.2	711.			
55							422.4	485.2	548.0	610.8	673.6	736.			
56							437.3	502.3	567.3	632.3	697.3	762.			
57							452.4	519.7	586.9	654.2	721.4	788.			
58							467.8	537.4	606.9	676.4	745.9	815.			
59							483.4	555.4	627.3	699.2	771.1	843.			
60							499.3	573.7	648.0	722.4	796.7	871.			
61								592.3	669.0	745.8	822.5	899.			
62								611.2	690.3	769.5	848.6	928.			
63								630.4	711.9	793.5	875.0	957.			
64								649.9	733.8	817.8	901.8	986.			
65								669.7	756.0	842.4	929.0	1016.			
66								689.8	778.6	867.4	956.6	1046.			
67								710.2	801.5	892.8	984.5	1077.			
68								730.9	824.8	918.6	1012.8	1107.			
69								751.9	848.5	944.8	1041.5	1138.			
70								773.2	872.6	971.4	1070.6	1170.			
71									897.1	998.4	1100.1	1202.			
72									921.9	1025.8	1129.9	1235.			
73									947.2	1053.6	1160.1	1268.			
74									972.8	1081.8	1190.8	1301.			
75									998.8	1110.4	1222.0	1335.			
76									1025.2	1139.4	1253.6	1369.			
77									1052.0	1168.8	1285.6	1404.			
78									1079.2	1198.6	1318.0	1439.			
79									1106.8	1228.8	1350.8	1475.			
80									1134.8	1259.4	1384.0	1511.			
81										1290.4	1417.6	1547.			
82										1321.8	1451.6	1584.			
83										1353.6	1486.0	1621.			
84										1385.8	1520.8	1658.			
85										1418.4	1556.0	1696.			
86										1451.4	1591.6	1735.			
87										1484.8	1627.6	1775.			
88										1518.6	1664.0	1816.			
89										1552.8	1700.8	1857.			
90										1587.4	1738.0	1899.			
91											1775.6	1941.			
92											1813.6	1983.			
93											1852.0	2026.			
94											1890.8	2069.			
95											1930.0	2113.			
96											1969.6	2158.			
97											2009.6	2203.			
98											2050.0	2248.			
99											2090.8	2294.			
100											2132.0	2340.			
101												2387.			
102												2434.			
103												2482.			
104												2530.			
105												2579.			
106												2628.			
107												2678.			
108												2728.			
109												2779.			
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GROSS INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP OIB-UNBORKED TREES
YELLOW PINE
SANTA FE-CARSON-LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	RATIO TREES
7	1.0	2.1	3.2	4.3	5.3	6.4	7.5									0
8	2.8	5.8	8.8	11.8	14.9	17.9	20.9	23.9								1
9	4.8	10.2	15.6	21.0	26.4	31.8	37.2	42.7	48.1							0
10		15.2	23.4	31.6	39.7	47.9	56.1	64.3	72.5							3
11		20.8	32.1	43.4	54.7	66.0	77.3	88.5	99.8	111.1						1
12		27.0	41.7	56.5	71.2	85.9	100.6	115.4	130.1	144.8						1
13		33.7	52.2	70.7	89.2	107.7	126.2	144.7	163.2	181.7	200.2					4
14		41.0	63.6	86.2	108.7	131.3	153.9	176.5	199.0	221.6	244.2					3
15			75.8	102.8	129.8	156.8	183.7	210.7	237.7	264.6	291.6	318.6				3
16			88.9	120.6	152.3	184.0	215.7	247.4	279.1	310.7	342.4	374.1				7
17			102.9	139.6	176.3	213.0	249.8	286.5	323.2	359.9	396.6	433.3	470.1			11
18			117.7	159.8	201.8	243.9	286.0	328.0	370.1	412.1	454.2	496.2	538.3			7
19			133.4	181.1	228.8	276.6	324.3	372.0	419.7	467.4	515.1	562.8	610.5	658.2		16
20				203.7	257.3	311.0	364.7	418.4	472.0	525.7	579.4	633.1	686.8	740.4		10
21				227.4	287.3	347.3	407.2	467.2	527.1	587.1	647.1	707.0	767.0	826.9	886.9	14
22				252.2	318.8	385.3	451.9	518.4	585.0	651.5	718.1	784.6	851.2	917.7	984.3	15
23				278.3	351.8	425.2	498.7	572.1	645.6	719.0	792.5	866.0	939.4	1012.9	1086.3	9
24				305.5	386.2	466.9	547.6	628.2	708.9	789.6	870.3	950.9	1031.6	1112.3	1193.0	17
25					422.2	510.4	598.6	686.8	775.0	863.2	951.4	1039.6	1127.8	1216.0	1304.2	15
26					459.6	555.7	651.7	747.8	843.8	939.9	1035.9	1132.0	1228.0	1324.1	1420.1	14
27					498.6	602.8	707.0	811.2	915.4	1019.6	1123.8	1228.0	1332.2	1436.4	1540.7	14
28					539.0	651.7	764.3	877.0	989.7	1102.4	1215.1	1327.8	1440.4	1553.1	1665.8	4
29					580.9	702.4	823.8	945.3	1066.8	1188.2	1309.7	1431.2	1552.6	1674.1	1795.6	0
30						754.9	885.5	1016.0	1146.6	1277.2	1407.7	1538.3	1668.9	1799.4	1930.0	0
31						809.2	949.2	1089.2	1229.2	1369.1	1509.1	1649.1	1789.1	1929.0	2069.0	6
32						865.4	1015.1	1164.8	1314.5	1464.2	1613.9	1763.6	1913.3	2063.0	2212.7	2
33						923.3	1083.0	1242.8	1402.5	1562.3	1722.0	1881.7	2041.5	2201.2	2361.0	1
34						983.1	1153.1	1323.2	1493.3	1663.4	1833.5	2003.6	2173.7	2343.8	2513.9	2
35							1225.4	1406.1	1586.9	1767.7	1948.4	2129.2	2309.9	2490.7	2671.4	0
36							1299.7	1491.5	1683.2	1874.9	2066.7	2258.4	2450.2	2641.9	2833.6	0
37							1376.2	1579.2	1782.3	1985.3	2188.3	2391.4	2594.4	2797.4	3000.5	0
38							1454.8	1669.4	1884.1	2098.7	2313.4	2528.0	2742.6	2957.3	3171.9	0
39							1535.5	1762.1	1988.6	2215.2	2441.8	2668.3	2894.9	3121.4	3348.0	0
40								1857.2	2096.0	2334.7	2573.5	2812.3	3051.1	3289.9	3528.7	0
41								1954.7	2206.0	2457.4	2708.7	2960.0	3211.4	3462.7	3714.1	0
42								2054.6	2318.8	2583.0	2847.2	3111.4	3375.6	3639.8	3904.0	0
43								2157.0	2434.4	2711.8	2989.2	3266.5	3543.9	3821.3	4098.7	0
44								2261.9	2552.7	2843.6	3134.5	3425.3	3716.2	4007.1	4297.9	0
45									2673.8	2978.5	3283.1	3587.8	3892.5	4197.1	4501.8	0
46									2797.6	3116.4	3435.2	3754.0	4072.8	4391.6	4710.3	0
47									2924.2	3257.4	3590.6	3923.9	4257.1	4590.3	4923.5	0
48									3053.5	3401.5	3749.5	4097.4	4445.4	4793.3	5141.3	0
49									3185.6	3548.6	3911.7	4274.7	4637.7	5000.7	5363.7	0
50									3320.5	3698.8	4077.2	4455.6	4834.0	5212.4	5590.8	0
BASIS TREES	0	0	5	8	16	36	43	38	2·	15	9	2	1	0	0	

YELLOW PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.2	.8	1.5	2.4	3.4	4.5	5.6									
8	.6	2.1	4.1	6.6	9.4	12.5	15.7	19.0								
9	1.0	3.6	7.2	11.7	16.7	22.1	27.9	33.8	39.8							
10		5.2	10.7	17.4	25.0	33.2	41.8	50.8	59.8							
11		7.0	14.9	23.7	34.2	45.5	57.5	69.8	82.2	95.6						
12		9.0	18.7	30.7	44.3	59.1	74.7	90.7	107.1	123.7						
13		11.1	23.2	38.3	55.2	73.9	93.4	113.6	134.2	155.0	175.8					
14		13.3	28.1	46.4	67.2	89.8	113.7	138.3	163.4	188.8	214.2					
15			33.3	55.1	79.9	106.9	135.4	164.9	194.9	225.3	255.7	286.2				
16			38.8	64.3	93.5	125.2	158.7	193.3	228.6	264.3	300.1	335.8				
17			44.6	74.1	107.9	144.7	183.5	223.6	264.5	305.8	347.3	388.8	430.1			
18			50.7	84.5	123.2	165.3	209.7	255.7	302.6	349.9	397.5	445.2	492.6			
19			57.2	95.5	139.2	187.1	237.5	289.6	342.8	396.6	450.5	504.3	558.0	611.5		
20				107.0	156.3	210.0	266.7	325.4	385.3	445.8	506.5	567.2	627.7	687.7		
21				119.1	174.2	234.1	297.5	363.0	429.9	497.5	565.4	633.2	700.8	767.9	834.1	
22				131.8	192.9	259.4	329.7	402.5	476.8	551.8	627.2	702.5	777.5	852.1	925.4	
23				145.0	212.4	285.4	363.5	443.4	525.8	608.7	691.9	775.0	857.8	940.1	1021.8	
24				158.8	232.8	312.9	398.7	487.0	577.1	668.1	759.5	851.8	943.8	1035.5	1126.9	
25					254.1	342.3	435.9	532.2	631.5	730.1	830.1	929.9	1029.4	1128.8	1228.1	
26					276.2	372.3	473.8	578.9	686.0	794.0	902.6	1011.0	1118.9	1226.8	1334.4	
27					299.1	403.4	513.5	627.0	744.0	861.7	979.9	1097.7	1215.0	1331.9	1448.5	
28					323.1	435.8	554.9	678.0	804.1	931.4	1059.2	1186.8	1314.0	1440.8	1566.7	
29					348.2	469.3	597.7	730.7	866.4	1003.4	1141.4	1279.	1416.1	1552.7	1688.5	
30						504.0	642.0	785.0	931.0	1078.4	1226.8	1374.5	1521.8	1668.6	1814.7	
31						540.0	687.9	841.1	997.6	1155.8	1314.6	1473.1	1630.8	1788.	1944.7	
32						577.3	735.2	899.3	1066.4	1235.3	1404.8	1574.0	1742.8	1910.9	2078.	
33						615.9	784.4	959.1	1137.7	1318.0	1498.4	1678.4	1858.1	2037.4	2216.3	
34						655.7	835.6	1020.8	1211.1	1402.3	1593.4	1784.3	1974.8	2165.	2354.5	
35							888.0	1084.5	1286.6	1489.7	1692.4	1894.8	2096.8	2298.5	2499.8	
36							942.5	1150.	1364.4	1579.8	1794.8	2009.4	2223.6	2437.4	2650.8	
37							998.0	1217.7	1444.4	1672.4	1900.1	2127.4	2354.3	2580.8	2806.9	
38							1054.7	1286.6	1525.6	1766.2	2007.1	2247.6	2487.6	2727.2	2966.4	
39							1113.5	1357.7	1609.8	1863.3	2117.3	2370.8	2623.8	2876.4	3128.5	
40							1173.4	1430.5	1695.5	1962.4	2229.2	2495.5	2761.3	3026.7	3291.7	
41							1234.9	1505.2	1783.4	2064.5	2344.5	2624.1	2903.2	3181.8	3460.0	
42							1298.2	1581.8	1873.3	2168.0	2462.1	2755.7	3048.8	3341.5	3633.8	
43							1362.9	1660.3	1965.5	2274.2	2581.4	2888.1	3194.3	3500.0	3805.3	
44							1429.1	1740.4	2059.8	2382.7	2704.9	3026.6	3347.8	3668.5	3988.8	
45								1822.1	2156.7	2494.6	2831.9	3168.7	3505.0	3840.8	4176.2	
46								1905.4	2255.2	2608.4	2961.1	3313.3	3665.0	4016.2	4367.0	
47								1990.3	2355.3	2724.3	3092.8	3460.8	3828.3	4195.3	4561.8	
48								2076.8	2457.0	2841.7	3226.0	3610.0	3993.5	4376.5	4759.1	
49								2164.9	2560.2	2960.9	3361.3	3761.3	4160.9	4560.1	4958.0	
50								2254.7	2665.0	3081.8	3498.2	3914.2	4329.8	4744.9	5159.5	
51								2346.2	2771.4	3204.2	3637.5	4070.4	4502.8	4934.8	5366.4	
52								2439.4	2879.4	3328.9	3778.2	4227.1	4675.5	5123.4	5570.9	
53								2534.3	2989.0	3455.1	3920.5	4385.4	4849.8	5313.7	5777.2	
54								2630.8	3100.1	3582.8	4064.3	4546.3	5027.8	5508.8	5989.3	
55									3212.8	3712.0	4209.6	4707.8	5205.5	5702.7	6199.4	
56									3327.1	3842.7	4356.5	4869.9	5383.8	5897.3	6410.3	
57									3443.0	3975.0	4504.8	5033.9	5563.5	6093.6	6623.3	
58									3560.6	4108.8	4654.4	5198.3	5743.5	6289.3	6834.6	
59									3679.8	4244.1	4805.0	5363.3	5923.9	6485.0	7046.5	
60									3800.7	4380.9	4956.7	5529.0	6104.7	6681.1	7257.9	
61									3923.3	4519.3	5109.9	5695.9	6287.3	6877.8	7469.8	
62									4047.5	4659.2	5264.5	5863.3	6470.5	7075.2	7681.4	
63									4173.4	4800.7	5420.6	6031.2	6653.3	7273.0	7893.3	
64									4300.9	4943.6	5578.1	6199.6	6836.6	7471.2	8106.3	
65										5087.9	5737.1	6369.4	7020.4	7670.0	8319.1	
66										5233.7	5897.5	6540.0	7204.8	7870.1	8535.0	
67										5380.9	6059.3	6711.2	7390.0	8069.3	8748.3	
68										5529.5	6222.4	6883.0	7575.8	8269.1	8962.1	
69										5679.6	6386.8	7095.6	7762.1	8469.1	9176.6	
70										5831.2	6552.6	7273.6	7949.1	8669.1	9391.6	
71											6719.8	7452.1	8136.7	8869.7	9607.2	
72											6888.4	7631.1	8325.1	9070.8	9823.4	
73											7058.4	7810.6	8513.9	9272.6	10040.0	
74											7229.7	7990.5	8703.2	9474.8	10257.1	
75											7402.3	8170.8	8892.8	9677.4	10474.5	
76											7576.2	8351.5	9082.8	9880.4	10692.3	
77											7751.4	8532.6	9273.2	10083.8	10910.4	
78											7927.8	8714.0	9463.9	10287.5	11128.8	
79											8105.4	8895.7	9655.0	10491.5	11347.5	
80											8284.2	9077.7	9846.3	10695.8	11566.5	
81												9259.9	10037.8	10900.3	11785.8	
82												9442.3	10229.5	11105.0	12005.3	
83												9624.9	10421.4	11309.9	12225.0	
84												9807.8	10613.5	11515.0	12444.9	
85												9991.0	10805.8	11720.2	12665.0	
86												10174.4	10998.3	11925.6	12885.3	
87												10358.0	11191.0	12131.2	13105.8	
88												10541.8	11383.9	12336.9	13326.5	
89												10725.8	11577.0	12542.8	13547.4	
90												10910.0	11770.3	12748.8	13768.4	

NET INTERNATIONAL 1/4 INCH RULE VOLUME

YELLOW PINE

LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS														
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	TALL
7	.5	1.2	2.1	3.0	4.1	5.2	6.3								
8	1.3	3.3	5.7	8.2	11.2	14.3	17.4	20.6							
9	2.2	5.5	9.8	14.6	19.7	25.2	30.8	36.6	42.4						
10		8.2	14.5	21.6	29.4	37.6	46.1	54.8	63.6						
11		10.9	19.5	29.2	39.9	51.3	63.0	75.0	87.2	99.5					
12		13.7	24.8	37.5	51.4	66.2	81.5	97.2	113.2	129.3					
13		16.7	30.4	46.3	63.7	82.2	101.5	121.3	141.4	161.8	181.8				
14		19.8	36.3	55.6	76.9	99.5	123.0	147.2	171.7	196.4	221.3				
15			42.5	65.4	90.8	117.8	145.9	174.9	204.2	233.8	263.6	293.7			
16			49.0	75.8	105.5	137.2	170.3	204.3	238.9	273.7	308.7	343.9			
17			55.6	86.6	120.9	157.7	196.1	235.5	275.6	316.1	356.7	397.5	437.7		
18			62.6	97.9	137.1	179.2	223.2	268.5	314.5	360.4	407.5	454.1	500.5		
19			69.7	109.6	154.1	201.8	251.8	303.2	355.5	408.3	461.2	514.1	567.8	621.2	
20				121.8	171.8	225.5	281.7	339.7	398.6	458.2	517.7	577.3	636.7	695.8	
21				134.5	190.3	250.2	313.1	377.9	443.8	510.3	577.0	643.7	710.2	776.3	841.9
22				147.7	209.5	276.0	345.9	417.8	491.1	565.0	639.2	713.3	787.3	861.2	934.7
23				161.3	229.5	302.9	380.0	459.5	540.5	622.2	704.3	786.2	867.8	948.9	1029.7
24				175.4	250.2	330.9	415.6	503.0	592.0	681.9	772.1	862.2	952.1	1041.7	1130.9
25					271.7	359.9	452.6	548.2	645.7	744.0	842.8	941.4	1039.7	1137.4	1234.5
26					294.0	390.0	491.0	595.2	701.4	808.7	916.3	1023.6	1130.6	1237.5	1343.4
27					317.0	421.2	530.9	644.0	759.4	875.8	992.7	1109.5	1225.9	1341.8	1456.5
28					340.9	453.6	572.1	694.6	819.4	945.5	1072.0	1198.4	1324.4	1448.8	1574.0
29					365.6	487.0	614.9	747.0	881.6	1017.6	1154.2	1290.6	1426.5	1561.6	1695.7
30						521.6	659.1	801.1	946.0	1092.3	1239.2	1385.7	1532.1	1677.5	1821.8
31						557.2	704.7	857.1	1012.5	1169.5	1327.1	1484.6	1641.4	1797.4	1952.2
32						594.1	751.8	914.3	1081.2	1249.2	1417.9	1586.4	1754.3	1921.5	2086.9
33						632.0	800.4	974.5	1152.1	1331.9	1511.6	1691.6	1870.8	2049.6	2225.9
34						671.2	850.5	1036.0	1225.2	1416.3	1608.2	1800.0	1990.4	2180.8	2369.3
35							902.1	1099.3	1301.4	1503.7	1707.7	1911.5	2114.7	2316.5	2516.9
36							955.2	1164.4	1377.9	1593.6	1810.1	2026.5	2242.1	2456.3	2668.9
37							1009.7	1231.4	1457.5	1686.1	1915.5	2144.7	2373.1	2600.0	2825.3
38							1065.8	1300.2	1539.4	1781.1	2023.7	2266.2	2507.7	2747.7	2986.0
39							1123.4	1370.9	1623.5	1878.7	2134.9	2391.8	2646.0	2899.4	3151.0
40								1443.5	1709.7	1978.9	2249.0	2519.0	2787.9	3055.1	3320.4
41								1517.9	1798.2	2081.6	2366.1	2650.3	2933.4	3214.8	3494.1
42								1594.2	1889.0	2186.9	2486.1	2785.0	3082.6	3378.5	3672.2
43								1672.4	1981.9	2294.8	2609.0	2922.9	3235.5	3546.2	3854.6
44								1752.4	2077.1	2405.3	2734.8	3064.1	3392.0	3717.9	4041.4
45									2174.5	2518.4	2863.6	3208.6	3552.2	3893.6	4232.5
46									2274.2	2634.1	2995.4	3356.4	3716.0	4073.3	4428.0
47									2376.0	2752.3	3130.1	3507.5	3883.4	4257.0	4627.8
48									2480.1	2873.1	3267.7	3661.9	4054.5	4444.7	4832.0
49									2586.5	2996.6	3408.3	3819.6	4229.3	4636.4	5040.5
50									2695.1	3122.5	3551.8	3980.6	4407.7	4832.2	5253.4
BASIS TREES	0	0	3	8	13	30	40	35	25	12	7	4	1	0	1

YELLOW PINE

SANTA FE-CARSON-LINCOLN-GOTHAM-TONTO N.F.

DBH CLASS	HEIGHT CLASS															BASIC
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
7	.6	1.2	1.8	2.4	3.0	3.5	4.1									
8	1.8	3.7	5.6	7.6	9.5	11.4	13.4	15.3								
9	3.3	7.1	10.9	14.7	18.5	22.3	26.1	29.9	33.7							
10		11.3	17.4	23.5	29.6	35.7	41.8	47.9	53.9							
11		16.2	25.0	33.8	42.5	51.3	60.1	68.9	77.7	86.5						
12		21.7	33.6	45.4	57.3	69.1	80.9	92.8	104.6	116.5						
13		27.8	43.1	58.3	73.6	88.8	104.1	119.4	134.6	149.9	165.2					
14		34.5	53.5	72.4	91.4	110.3	129.3	148.2	167.2	186.2	205.1					
15			64.9	88.0	111.1	134.1	157.2	180.3	203.4	226.5	249.6	272.7				
16			77.2	104.6	132.1	159.5	187.1	214.5	241.9	269.3	296.7	324.1				
17			90.3	122.5	154.7	186.9	219.1	251.3	283.5	315.8	348.0	380.2	412.4			
18			104.3	141.6	178.8	216.1	253.3	290.6	327.8	365.1	402.3	439.6	476.8			
19			119.2	161.8	204.4	247.0	289.6	332.2	374.9	417.5	460.1	502.7	545.3	587.9		
20				183.0	231.2	279.3	327.5	375.6	423.8	472.0	520.1	568.3	616.5	664.7		
21				205.3	259.1	313.0	366.9	420.8	474.7	528.7	582.6	636.5	690.4	744.3	798.2	
22				229.6	289.6	349.7	409.7	469.8	529.8	589.9	649.9	709.9	769.9	829.9	889.8	
23				255.7	322.4	389.1	455.8	522.5	589.2	655.9	722.6	789.3	855.9	922.6	989.3	
24				283.6	357.5	431.4	505.3	579.2	653.1	727.0	801.0	874.9	948.8	1022.8	1096.7	
25				313.4	395.0	476.7	558.3	639.9	721.5	803.1	884.7	966.3	1047.9	1129.5	1211.1	
26					434.5	524.3	614.1	703.9	793.7	883.5	973.3	1063.1	1152.9	1242.7	1332.5	
27					476.0	574.4	672.8	771.2	869.6	967.9	1066.3	1164.7	1263.1	1361.5	1459.9	
28					519.5	627.1	734.7	842.3	949.9	1057.5	1165.1	1272.7	1380.3	1487.9	1595.5	
29					565.0	682.0	799.0	916.0	1033.0	1150.0	1267.0	1384.0	1501.0	1618.0	1735.0	
30					612.5	739.5	866.5	993.5	1120.5	1247.5	1374.5	1501.5	1628.5	1755.5	1882.5	
31					662.0	799.4	936.8	1074.2	1211.6	1349.0	1486.4	1623.8	1761.2	1898.6	2036.0	
32					713.5	861.3	1009.1	1156.9	1304.7	1452.5	1600.3	1748.1	1895.9	2043.7	2191.5	
33					767.0	925.8	1084.6	1243.4	1402.2	1560.9	1719.7	1878.5	2037.3	2196.1	2354.9	
34					822.4	992.9	1163.4	1333.9	1504.4	1674.9	1845.4	2015.9	2186.4	2356.9	2527.4	
35					879.8	1062.3	1244.8	1427.3	1609.8	1792.3	1974.8	2157.3	2339.8	2522.3	2704.8	
36					939.2	1133.6	1328.0	1522.4	1716.8	1911.2	2105.6	2300.0	2494.4	2688.8	2883.2	
37					1000.5	1207.8	1415.1	1622.4	1829.7	2037.0	2244.3	2451.6	2658.9	2866.2	3073.5	
38					1063.8	1284.0	1504.2	1724.4	1944.6	2164.8	2385.0	2605.2	2825.4	3045.6	3265.8	
39					1129.0	1362.2	1595.4	1828.6	2061.8	2295.0	2528.2	2761.4	2994.6	3227.8	3461.0	
40					1196.2	1442.4	1688.6	1934.8	2181.0	2427.2	2673.4	2919.6	3165.8	3412.0	3658.2	
41					1265.3	1524.6	1783.9	2043.2	2302.5	2561.8	2821.1	3080.4	3339.7	3599.0	3858.3	
42					1336.4	1608.8	1881.2	2153.6	2426.0	2698.4	2970.8	3243.2	3515.6	3788.0	4060.4	
43					1409.5	1695.0	1980.5	2266.0	2551.5	2837.0	3122.5	3408.0	3693.5	3979.0	4264.5	
44					1484.6	1783.2	2081.8	2380.4	2679.0	2977.6	3276.2	3574.8	3873.4	4172.0	4470.6	
45					1561.7	1873.4	2185.1	2496.8	2808.5	3120.2	3431.9	3743.6	4055.3	4367.0	4678.7	
46					1640.8	1965.6	2290.4	2615.2	2940.0	3264.8	3589.6	3914.4	4239.2	4564.0	4888.8	
47					1721.9	2059.8	2397.7	2735.6	3073.5	3411.4	3749.3	4087.2	4425.1	4763.0	5100.9	
48					1805.0	2156.0	2507.0	2858.0	3209.0	3560.0	3911.0	4262.0	4613.0	4964.0	5315.0	
49					1890.1	2254.2	2618.3	2982.4	3346.5	3710.6	4074.7	4438.8	4802.9	5167.0	5531.1	

NET SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB
YELLOW PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BA I TR
7	.1	.2	.6	1.0	1.6	2.2	2.8									0
8	.2	.6	1.7	3.3	5.1	7.0	9.1	11.3								0
9	.3	1.1	3.3	6.3	9.8	13.6	17.7	22.0	26.4							0
10		1.7	5.2	9.9	15.5	21.7	28.3	35.1	42.2							0
11		2.3	7.3	14.1	22.1	31.1	40.6	50.5	60.6	70.8						0
12		2.9	9.6	18.8	29.6	41.6	54.4	67.8	81.4	95.2						0
13		3.6	12.2	23.9	37.8	53.3	69.8	87.0	104.6	122.3	140.1					0
14		4.3	14.9	29.4	46.8	66.0	86.6	108.0	129.9	152.1	174.3					0
15			17.8	35.4	56.4	79.8	104.8	130.8	157.5	184.4	211.4	238.3				0
16			20.9	41.8	66.8	94.7	124.4	155.4	187.1	219.2	251.3	283.4				0
17			24.1	48.6	77.9	110.5	145.4	181.7	218.9	256.5	294.2	331.8	369.2			4
18			27.5	55.8	89.6	127.3	167.7	209.7	252.7	296.2	339.8	383.4	426.7			1
19			31.1	63.4	102.0	145.2	191.3	239.4	288.6	338.4	388.3	438.1	487.7	536.8		1
20				71.3	115.1	164.0	216.3	270.8	326.6	383.0	439.6	496.1	552.2	607.9		6
21				79.7	128.9	183.8	242.6	303.8	366.6	430.0	493.7	557.2	620.3	682.9	744.8	4
22				88.5	143.3	204.6	270.2	338.6	408.6	479.5	550.5	621.4	691.9	761.8	830.9	4
23				97.7	158.5	226.4	299.2	375.0	452.7	531.3	610.2	688.8	767.0	844.5	921.3	5
24				107.2	174.3	249.2	329.5	413.2	498.9	585.6	672.6	759.4	845.7	931.2	1015.8	3
25					190.8	273.0	361.1	453.0	547.1	642.3	737.8	833.1	927.8	1021.7	1114.6	4
26					207.9	297.8	394.1	494.5	597.3	701.4	805.8	909.9	1013.4	1116.1	1217.6	5
27					225.8	323.6	428.4	537.7	649.6	762.9	876.5	989.9	1102.6	1214.3	1324.9	3
28					244.3	350.3	464.0	582.5	703.9	826.8	950.1	1073.0	1195.3	1316.4	1436.3	1
29					263.5	378.1	500.9	629.1	760.3	893.1	1026.4	1159.3	1291.4	1422.4	1552.0	1
30						406.9	539.2	677.3	818.7	961.8	1105.4	1248.7	1391.1	1532.2	1671.9	0
31						436.7	578.9	727.2	879.2	1033.0	1187.3	1341.3	1494.2	1645.9	1796.0	0
32						467.4	619.8	778.8	941.7	1106.5	1271.9	1436.9	1600.9	1763.4	1924.3	0
33						499.2	662.1	832.1	1006.3	1182.5	1359.4	1535.8	1711.1	1884.9	2056.9	0
34						532.0	705.8	887.1	1072.9	1260.9	1449.5	1637.7	1824.8	2010.1	2193.6	0
35							750.8	943.8	1141.6	1341.7	1542.5	1742.8	1941.9	2139.3	2334.6	0
36							797.1	1002.2	1212.3	1424.9	1638.3	1851.1	2062.6	2272.3	2479.8	0
37							844.8	1062.2	1285.0	1510.5	1736.8	1962.5	2186.8	2409.1	2629.2	0
38							893.8	1124.0	1359.9	1598.6	1838.1	2077.0	2314.5	2549.8	2782.8	0
39							944.2	1187.5	1436.7	1689.0	1942.2	2194.7	2445.7	2694.4	2940.6	0
40								1252.6	1515.7	1781.9	2049.0	2315.5	2580.4	2842.9	3102.7	0
41								1319.5	1596.7	1877.2	2158.7	2439.5	2718.6	2995.2	3269.0	0
42								1388.0	1679.7	1974.9	2271.1	2566.6	2860.3	3151.3	3439.4	0
43								1458.3	1764.8	2075.0	2386.3	2696.9	3005.5	3311.4	3614.1	0
44								1530.2	1852.0	2177.6	2504.3	2830.3	3154.2	3475.3	3793.1	0
45									1941.2	2282.5	2625.1	2966.8	3306.4	3643.0	3976.2	0
46									2032.4	2389.9	2748.7	3106.5	3462.1	3814.6	4163.5	0
47									2125.8	2499.7	2875.0	3249.4	3621.4	3990.1	4355.1	0
48									2221.2	2612.0	3004.1	3395.3	3784.1	4169.5	4550.9	0
49									2318.6	2726.6	3136.0	3544.5	3950.4	4352.7	4750.9	0
50									2418.1	2843.7	3270.7	3696.8	4120.1	4539.8	4955.1	0
BASIS TREES	0	0	2	2	8	11	9	10	5	4	2	0	0	0	0	

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.2	.5	1.0	1.5	2.1	2.7	3.3									0
8	.7	1.6	3.0	4.7	6.5	8.5	10.5	12.6								1
9	1.3	3.0	5.7	8.9	12.5	16.4	20.4	24.5	28.7							0
10		4.5	8.8	13.9	19.7	25.8	32.3	38.9	45.7							1
11		6.2	12.3	19.6	27.9	36.7	46.0	55.6	65.4	75.2						1
12		7.9	15.9	25.8	36.9	48.9	61.4	74.4	87.5	100.8						1
13		9.6	19.8	32.4	46.7	62.1	78.3	95.0	112.0	129.2	146.3					4
14		11.3	23.9	39.5	57.2	76.4	96.6	117.4	138.7	160.1	181.6					2
15			28.0	46.9	68.3	91.7	116.2	141.6	167.5	193.5	219.7	245.8				1
16			32.3	54.6	80.1	107.9	137.2	167.4	198.3	229.4	260.7	291.8				6
17			36.7	62.6	92.5	125.0	159.4	194.9	231.2	267.7	304.4	341.0	377.4			2
18			41.1	71.0	105.4	143.0	182.8	224.0	266.0	308.4	350.9	393.3	435.5			7
19			45.6	79.6	118.9	161.9	207.5	254.7	302.8	351.4	400.2	448.8	497.2	545.2		17
20				88.5	133.0	181.7	233.4	286.9	341.6	396.8	452.1	507.3	562.3	616.8		2
21				97.7	147.6	202.4	260.5	320.8	382.3	444.4	506.8	569.0	630.8	692.2	753.1	12
22				107.1	162.7	223.9	288.8	356.2	425.0	494.4	564.1	633.7	702.8	771.5	839.5	12
23				116.9	178.4	246.3	318.4	393.2	469.6	546.8	624.2	701.4	778.3	854.5	930.1	3
24				126.9	194.7	269.5	349.1	431.7	516.1	601.4	686.9	772.3	857.2	941.4	1024.9	14
25					211.5	293.7	381.1	471.8	564.6	658.4	752.4	846.2	939.5	1032.1	1123.8	12
26					228.9	318.7	414.3	513.6	615.1	717.6	820.5	923.2	1025.3	1126.6	1226.9	10
27					246.9	344.6	448.7	556.9	667.5	779.2	891.4	1003.3	1114.5	1224.9	1334.2	13
28					265.5	371.4	484.4	601.8	721.8	843.2	964.9	1086.4	1207.2	1327.3	1445.7	2
29					284.7	399.2	521.3	648.3	778.1	909.5	1041.2	1172.7	1303.3	1433.6	1561.4	1
30						427.8	559.4	696.4	836.5	978.1	1120.2	1262.0	1402.9	1542.7	1681.3	1
31						457.4	598.9	746.1	896.8	1049.1	1201.9	1354.4	1506.0	1656.3	1805.3	1
32						487.9	639.6	797.5	959.0	1122.4	1286.4	1449.9	1613.5	1773.7	1933.4	1
33						519.3	681.6	850.5	1023.3	1198.2	1373.5	1548.5	1723.5	1895.1	2065.8	1
34						551.7	724.9	905.1	1089.6	1276.2	1463.5	1650.3	1835.9	2020.1	2202.9	2
35							769.4	961.4	1157.9	1356.7	1556.1	1755.1	1952.9	2149.3	2344.2	1
36							815.3	1019.4	1228.3	1439.6	1651.6	1863.1	2072.3	2281.2	2488.8	1
37							862.5	1079.3	1300.6	1524.8	1749.7	1974.2	2197.2	2418.8	2637.9	1
38							911.1	1140.3	1375.0	1610.5	1850.7	2088.4	2324.6	2558.8	2791.8	1
39							960.9	1203.3	1451.4	1702.5	1954.4	2205.7	2455.5	2703.8	2948.3	
40								1267.9	1529.9	1794.9	2060.9	2326.1	2589.9	2851.3	3111.2	
41								1334.3	1610.4	1889.8	2170.1	2449.8	2727.8	3003.4	3276.2	
42								1402.3	1693.0	1987.1	2282.1	2576.5	2869.1	3159.2	3446.4	
43								1472.0	1777.6	2086.7	2397.0	2706.4	3014.1	3319.1	3619.8	
44								1543.4	1864.2	2188.8	2514.8	2839.5	3162.4	3482.6	3799.9	
45									1953.0	2293.4	2634.9	2975.7	3314.3	3650.0	3981.1	
46									2043.8	2400.2	2758.1	3115.0	3469.7	3821.4	4169.5	
47									2136.6	2509.7	2884.2	3257.5	3628.6	3996.6	4360.8	
48									2231.5	2621.5	3012.8	3403.1	3791.1	4175.6	4556.3	
49									2328.5	2735.7	3144.3	3551.9	3957.1	4358.6	4756.2	
50									2427.6	2852.4	3278.6	3703.8	4126.4	4545.1	4960.1	
BASIS TREES	0	2	3	5	14	30	40	38	24	12	7	4	1			

TOTAL STEM GROSS CUBIC FOOT VOLUME-UNFORKED TREES
BLACKJACK PINE
LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.1															0
2	.2	.2														0
3	.3	.4	.6													0
4	.4	.7	1.0	1.4												0
5	.6	1.1	1.6	2.1	2.6											30
6	.8	1.5	2.2	2.9	3.7	4.4										63
7	1.1	2.0	3.0	4.0	4.9	5.9	6.9									73
8	1.4	2.6	3.9	5.2	6.4	7.7	9.0	10.2								77
9	1.7	3.3	4.9	6.5	8.1	9.7	11.3	12.9	14.5							67
10		4.0	6.0	8.0	10.0	12.0	14.0	15.9	17.9							74
11		4.9	7.3	9.7	12.1	14.5	16.9	19.3	21.7	24.1						91
12		5.8	8.6	11.5	14.4	17.2	20.1	22.9	25.8	28.6						95
13		6.8	10.1	13.5	16.8	20.2	23.5	26.9	30.3	33.6	37.0					30
14		7.9	11.7	15.6	19.5	23.4	27.3	31.2	35.1	39.0	42.8					26
15			13.5	17.9	22.4	26.9	31.3	35.8	40.2	44.7	49.2	53.6				23
16			15.3	20.4	25.5	30.5	35.6	40.7	45.8	50.9	55.9	61.0				19
17			17.3	23.0	28.7	34.5	40.2	45.9	51.7	57.4	63.1	68.9	74.6			12
18			19.4	25.8	32.2	38.6	45.1	51.5	57.9	64.3	70.8	77.2	83.6			23
19			21.6	28.7	35.9	43.0	50.2	57.4	64.5	71.7	78.8	86.0	93.2	100.3		13
20				31.8	39.8	47.7	55.6	63.6	71.5	79.4	87.4	95.3	103.2	111.2		9
21				35.1	43.8	52.6	61.3	70.1	78.8	87.6	96.3	105.0	113.8	122.5	131.3	5
22				38.5	48.1	57.7	67.3	76.9	86.5	96.1	105.7	115.3	124.9	134.5	144.1	12
23				42.1	52.5	63.0	73.5	84.0	94.5	105.0	115.5	126.0	136.5	147.0	157.5	3
24				45.8	57.2	68.6	80.1	91.5	102.9	114.3	125.8	137.2	148.6	160.0	171.5	6
25					62.1	74.5	86.9	99.3	111.7	124.1	136.4	148.8	161.2	173.6	186.0	2
26					67.1	80.5	93.9	107.3	120.8	134.2	147.6	161.0	174.4	187.8	201.2	2
27					72.4	86.8	101.3	115.8	130.2	144.7	159.1	173.6	188.1	202.5	217.0	1
28					77.8	93.4	108.9	124.5	140.0	155.6	171.1	186.7	202.2	217.8	233.3	0
29					83.5	100.2	116.9	133.5	150.2	166.9	183.6	200.3	216.9	233.6	250.3	1
30						107.2	125.0	142.9	160.7	178.6	196.4	214.3	232.2	250.0	267.9	0
31						114.5	133.5	152.6	171.6	190.7	209.8	228.8	247.9	266.9	286.0	0
32						121.9	142.3	162.6	182.9	203.2	223.5	243.8	264.1	284.4	304.7	0
33						129.7	151.3	172.9	194.5	216.1	237.7	259.3	280.9	302.5	324.1	0
34						137.7	160.6	183.5	206.4	229.4	252.3	275.2	298.2	321.1	344.0	0
35							170.2	194.5	218.8	243.1	267.4	291.7	316.0	340.3	364.6	0
36							180.0	205.7	231.4	257.1	282.9	308.6	334.3	360.0	385.7	0
37							190.2	217.3	244.5	271.6	298.8	325.9	353.1	380.2	407.4	0
38							200.6	229.2	257.9	286.5	315.1	343.8	372.4	401.1	429.7	0
39							211.3	241.4	271.6	301.8	331.9	362.1	392.3	422.4	452.6	0
40								254.0	285.7	317.4	349.2	380.9	412.7	444.4	476.1	0
41								266.8	300.2	333.5	366.9	400.2	433.5	466.9	500.2	0
42								280.0	315.0	350.0	385.0	420.0	454.9	489.9	524.9	0
43								293.5	330.2	366.8	403.5	440.2	476.9	513.5	550.2	0
44								307.3	345.7	384.1	422.5	460.9	499.3	537.7	576.1	0
45									361.6	401.7	441.9	482.1	522.2	562.4	602.6	0
46									377.8	419.8	461.8	503.7	545.7	587.7	629.6	0
47									394.4	438.2	482.1	525.9	569.7	613.5	657.3	0
48									411.4	457.1	502.8	548.5	594.2	639.9	685.6	0
49									428.7	476.3	523.9	571.6	619.2	666.8	714.4	0
50									446.4	496.0	545.5	595.1	644.7	694.3	743.9	0

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.1															0
2	.2	.2														0
3	.3	.4	.6													0
4	.4	.7	1.0	1.3												0
5	.6	1.1	1.6	2.1	2.5											2
6	.8	1.5	2.2	2.9	3.6	4.3										4
7	1.1	2.0	3.0	4.0	4.9	5.9	6.8									5
8	1.3	2.6	3.9	5.1	6.4	7.6	8.9	10.1								6
9	1.7	3.3	4.9	6.5	8.1	9.6	11.2	12.8	14.4							3
10		4.0	6.0	8.0	9.9	11.9	13.8	15.7	17.7							4
11		4.9	7.3	9.6	12.0	14.3	16.7	19.0	21.4	23.7						3
12		5.8	8.6	11.4	14.3	17.0	19.8	22.6	25.4	28.1						4
13		6.8	10.1	13.4	16.7	20.0	23.2	26.5	29.7	33.0	36.2					3
14		7.8	11.7	15.5	19.4	23.1	26.9	30.7	34.4	38.2	41.9					3
15			13.4	17.8	22.2	26.5	30.8	35.1	39.4	43.7	48.0	52.3				2
16			15.3	20.3	25.2	30.2	35.0	39.9	44.8	49.6	54.5	59.3				3
17			17.2	22.9	28.5	34.0	39.5	45.0	50.5	55.9	61.4	66.8	72.2			2
18			19.3	25.6	31.9	38.1	44.2	50.4	56.5	62.6	68.6	74.7	80.7			3
19			21.5	28.5	35.5	42.4	49.2	56.0	62.8	69.5	76.3	83.0	89.7	96.4		3
20				31.6	39.3	46.9	54.5	62.0	69.4	76.9	84.3	91.7	99.1	106.4		2
21				34.8	43.3	51.6	59.9	68.2	76.4	84.5	92.7	100.8	108.9	116.9	124.9	1
22				38.1	47.4	56.6	65.7	74.7	83.6	92.5	101.4	110.3	119.1	127.8	136.5	1
23				41.7	51.8	61.8	71.7	81.5	91.3	100.9	110.5	120.1	129.7	139.3	148.6	1
24				45.3	56.4	67.2	77.9	88.5	99.0	109.5	120.0	130.3	140.7	150.9	161.1	1
25					61.1	72.8	84.4	95.8	107.2	118.5	129.7	140.9	152.0	163.1	174.1	1
26					66.0	78.7	91.1	103.4	115.6	127.8	139.9	151.8	163.8	175.6	187.3	1
27					71.1	84.7	98.1	111.3	124.4	137.4	150.3	163.1	175.9	188.5	201.0	1
28					76.4	91.0	105.3	119.4	133.4	147.2	161.0	174.7	188.3	201.8	215.1	1
29					81.9	97.4	112.7	127.7	142.6	157.4	172.1	186.6	201.1	215.4	229.5	1
30						104.1	120.3	136.3	152.2	167.9	183.4	198.9	214.2	229.3	244.2	1
31						111.0	128.2	145.2	162.0	178.6	195.1	211.4	227.6	243.6	259.4	1
32						118.1	136.3	154.3	172.0	189.6	207.0	224.2	241.3	258.1	274.8	1
33						125.4	144.7	163.6	182.4	200.9	219.2	237.3	255.2	273.0	290.5	1
34						132.8	153.2	173.2	192.9	212.4	231.7	250.7	269.6	288.2	306.5	1
35							162.0	183.0	203.7	224.2	244.4	264.4	284.1	303.5	322.6	1
36							170.9	193.0	214.7	236.2	257.3	278.2	298.9	319.	339.	1
37							180.1	203.2	226.0	248.4	270.5	292.4	314.0	335.	356.	0
38							189.5	213.7	237.5	260.9	283.9	306.7	329.2	351.	372.	1
39							199.1	224.4	249.1	273.5	297.6	321.3	344.6	367.5	390.	1
40								235.2	261.0	286.4	311.4	336.	360.	384.	407.	1
41								246.3	273.1	299.5	325.4	351.	376.	400.	424.	1
42								257.5	285.4	312.8	339.7	366.1	392.	417.	442.	2
43								268.9	297.8	326.3	354.	381.	408.	434.	459.	1
44								280.6	310.5	339.8	368.6	396.8	424.	451.	477.	1
45									323.3	353.6	383.7	413.	442.	469.	496.	1
46									336.3	367.5	398.1	428.1	457.	486.	514.	1
47									349.4	381.6	413.1	443.9	474.	503.	532.	1
48									362.7	395.8	428.3	459.8	491.	521.	550.	1
49									376.1	410.2	443.4	475.8	507.	539.	568.	1
50									389.6	424.6	458.7	491.9	524.	557.	585.	1

BASIS TREES	0	1	2	3	4	5	6	7	8	9

TOTAL STEM NET CUBIC FOOT VOLUME
BLACKJACK PINE
COCONINO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.1															0
2	.2	.2														0
3	.3	.4	.6													0
4	.4	.7	1.0	1.4												3
5	.6	1.1	1.6	2.1	2.6											15
6	.8	1.5	2.2	2.9	3.7	4.4										26
7	1.1	2.0	3.0	4.0	4.9	5.9	6.9									34
8	1.4	2.6	3.9	5.2	6.4	7.7	9.0	10.2								34
9	1.7	3.3	4.9	6.5	8.1	9.7	11.3	12.9	14.5							28
10		4.0	6.0	8.0	10.0	12.0	13.9	15.9	17.9							34
11		4.9	7.3	9.7	12.1	14.5	16.9	19.2	21.6	24.0						17
12		5.8	8.6	11.5	14.4	17.2	20.0	22.9	25.7	28.5						26
13		6.8	10.1	13.5	16.8	20.2	23.5	26.8	30.1	33.4	36.7					11
14		7.9	11.7	15.6	19.5	23.4	27.3	31.1	34.9	38.7	42.5					16
15			13.5	17.9	22.4	26.8	31.3	35.7	40.1	44.4	48.7	52.9				11
16			15.3	20.4	25.5	30.5	35.6	40.6	45.6	50.5	55.4	60.2				10
17			17.3	23.0	28.7	34.4	40.1	45.8	51.4	57.0	62.4	67.8	73.1			5
18			19.4	25.8	32.2	38.6	45.0	51.3	57.6	63.8	69.9	75.9	81.8			6
19			21.6	28.7	35.9	43.0	50.1	57.2	64.2	71.1	77.8	84.5	91.0	97.4		3
20				31.8	39.7	47.6	55.5	63.3	71.0	78.7	86.1	93.5	100.6	107.7		4
21				35.1	43.8	52.5	61.2	69.8	78.3	86.7	94.9	102.9	110.7	118.4	126.1	3
22				38.5	48.0	57.6	67.1	76.5	85.9	95.0	104.0	112.7	121.3	129.6	138.0	7
23				42.0	52.5	62.9	73.3	83.6	93.8	103.8	113.5	123.0	132.2	141.3	150.3	1
24				45.8	57.2	68.5	79.8	91.0	102.1	112.9	123.5	133.7	143.6	153.4	163.1	4
25					62.0	74.3	86.6	98.7	110.7	122.4	133.8	144.8	155.5	166.0	176.3	2
26					67.1	80.4	93.6	106.8	119.7	132.3	144.5	156.3	167.8	178.9	190.0	1
27					72.3	86.7	100.9	115.1	129.0	142.5	155.6	168.2	180.4	192.3	204.1	1
28					77.7	93.2	108.5	123.7	138.6	153.1	167.1	180.6	193.5	206.1	218.6	0
29					83.4	99.9	116.4	132.6	148.6	164.1	179.0	193.3	207.0	220.4	233.5	2
30						106.9	124.5	141.9	158.9	175.4	191.3	206.4	220.9	235.0	248.8	0
31						114.2	132.9	151.5	169.6	187.1	203.9	219.9	235.2	250.0	264.5	0
32						121.6	141.6	161.3	180.6	199.2	216.9	233.8	249.9	265.3	280.5	0
33						129.3	150.6	171.5	191.9	211.6	230.3	248.1	264.9	281.1	296.9	0
34						137.3	159.8	181.9	203.6	224.3	244.1	262.7	280.3	297.2	313.6	0
35							169.3	192.7	215.5	237.5	258.2	277.7	296.1	313.6	330.7	0
36							179.0	203.8	227.9	250.9	272.7	293.1	312.2	330.4	348.1	0
37							189.1	215.2	240.5	264.7	287.5	308.8	328.6	347.4	365.8	0
38							199.4	226.9	253.5	278.9	302.7	324.8	345.4	364.8	383.7	0
39							209.9	238.8	266.8	293.4	318.3	341.2	362.5	382.5	401.9	0
40								251.1	280.4	308.3	334.2	358.0	379.9	400.5	420.4	0
41								263.7	294.4	323.4	350.4	375.0	397.6	418.8	439.1	0
42								276.6	308.7	339.0	366.9	392.4	415.7	437.3	458.1	0
43								289.7	323.3	354.8	383.8	410.1	434.0	456.1	477.3	0
44								303.2	338.2	371.0	401.1	428.1	452.6	475.1	496.6	0
45									353.4	387.5	418.6	446.5	471.4	494.3	516.2	0
46									368.9	404.3	436.5	465.1	490.5	513.8	535.9	0
47									384.8	421.5	454.6	484.0	509.9	533.5	555.8	0
48									401.0	438.9	473.1	503.2	529.6	553.3	575.8	0
49									417.5	456.7	491.9	522.7	549.4	573.4	596.0	0
50									434.2	474.8	511.0	542.4	569.5	593.6	616.2	0

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.1															
2	.2	.2														
3	.3	.4	.6													
4	.4	.7	1.0	1.4												
5	.6	1.1	1.6	2.1	2.6											
6	.8	1.5	2.2	2.9	3.7	4.4										
7	1.1	2.0	3.0	4.0	4.9	5.9	6.9									
8	1.3	2.6	3.9	5.2	6.4	7.7	9.0	10.2								
9	1.7	3.3	4.9	6.5	8.1	9.7	11.3	12.9	14.5							
10		4.0	6.0	8.0	10.0	12.0	14.0	15.9	17.9							
11		4.9	7.3	9.7	12.1	14.5	16.9	19.3	21.7	24.1						
12		5.8	8.6	11.5	14.3	17.2	20.0	22.9	25.7	28.6						
13		6.8	10.1	13.5	16.8	20.2	23.5	26.8	30.2	33.5	36.9					
14		7.8	11.7	15.6	19.5	23.4	27.2	31.1	35.0	38.8	42.7					
15			13.4	17.9	22.3	26.8	31.2	35.7	40.1	44.5	49.0	53.4				
16			15.3	20.3	25.4	30.4	35.5	40.5	45.6	50.6	55.6	60.7				
17			17.2	22.9	28.6	34.3	40.0	45.7	51.4	57.1	62.7	68.4	74.1			
18			19.3	25.7	32.0	38.4	44.8	51.1	57.5	63.8	70.2	76.5	82.8			
19			21.5	28.6	35.7	42.7	49.8	56.9	63.9	71.0	78.0	85.1	92.1	99.1		
20				31.6	39.4	47.3	55.1	62.9	70.7	78.5	86.2	94.0	101.7	109.4		
21				34.8	43.4	52.0	60.6	69.2	77.7	86.3	94.8	103.3	111.8	120.2	128.7	
22				38.1	47.6	57.0	66.4	75.7	85.1	94.4	103.7	112.9	122.0	131.4	140.6	
23				41.6	51.9	62.1	72.3	82.5	92.7	102.8	112.9	122.9	133.	143.	152.9	
24				45.2	56.3	67.5	78.5	89.6	100.6	111.5	122.4	133.2	144.1	154.9	165.6	
25					61.0	73.0	85.0	96.9	108.7	120.5	132.2	143.9	155.5	167.1	178.6	
26					65.8	78.7	91.6	104.4	117.1	129.8	142.3	154.8	167.3	179.7	192.	
27					70.8	84.6	98.4	112.1	125.7	139.3	152.7	166.1	179.4	192.5	205.	
28					75.9	91.8	105.5	120.1	134.6	149.1	163.4	177.6	191.7	205.	219.6	
29					81.2	97.0	112.8	128.3	143.8	159.1	174.3	189.4	204.4	219.	233.9	
30						103.5	120.2	136.8	153.3	169.4	185.5	201.4	217.2	232.	248.5	
31						110.2	127.9	145.4	162.8	180.2	197.3	213.9	230.5	247.	263.4	
32						117.0	135.8	154.3	172.7	190.8	208.7	226.5	244.	261.4	278.5	
33						124.1	143.9	163.4	182.8	201.9	220.7	239.4	257.8	276.	293.9	
34						131.3	152.2	172.8	193.1	213.2	233.0	252.6	271.8	290.9	309.9	
35							160.7	182.3	203.7	224.7	245.5	266.1	286.3	306.	325.6	
36							169.3	192.1	214.5	236.5	258.3	279.8	301.	321.8	341.8	
37							178.0	202.0	225.5	248.6	271.6	294.3	315.5	337.2	358.3	
38							187.4	212.0	236.7	260.8	284.8	308.7	332.4	355.9	379.3	
39							196.5	222.0	248.1	273.3	298.4	323.4	348.2	372.9	397.4	
40								232.1	259.8	285.9	311.5	336.6	361.	385.	409.9	
41								243.9	271.6	298.8	325.4	351.4	376.8	401.8	426.	
42								254.8	283.6	311.8	339.4	366.	392.6	418.	443.0	
43								265.9	295.8	325.3	354.2	382.4	409.6	436.	461.6	
44								277.1	308.1	338.8	368.9	398.4	426.7	454.	480.6	
45									320.7	352.9	384.4	414.9	444.1	472.	499.7	
46									333.9	367.5	400.4	432.1	462.6	492.	520.7	
47									348.1	382.9	417.2	450.2	482.0	512.6	542.8	
48									362.4	398.6	434.4	468.8	501.9	533.8	565.3	
49									377.0	414.9	452.3	488.1	522.5	555.6	588.4	
50									391.8	431.1	469.9	507.1	543.0	577.5	611.6	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNFORKED TREES
BLACKJACK PINE
LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.4	.7	.9	1.2	1.5											39
6	.6	1.1	1.7	2.2	2.8	3.4										53
7	.8	1.6	2.5	3.3	4.2	5.0	5.9									73
8	1.0	2.2	3.4	4.5	5.7	6.9	8.0	9.2								77
9	1.3	2.8	4.3	5.9	7.4	8.9	10.4	11.9	13.5							57
10		3.5	5.4	7.3	9.2	11.1	13.0	15.0	16.9							74
11		4.2	6.6	8.9	11.2	13.6	15.9	18.2	20.6	22.9						51
12		5.0	7.8	10.6	13.4	16.2	19.0	21.8	24.6	27.4						55
13		5.9	9.2	12.5	15.8	19.1	22.4	25.7	29.0	32.3	35.6					30
14		6.8	10.7	14.5	18.4	22.2	26.1	29.9	33.7	37.6	41.4					29
15			12.3	16.7	21.1	25.5	30.0	34.4	38.8	43.2	47.6	52.1				23
16			13.9	19.0	24.0	29.1	34.1	39.2	44.2	49.2	54.3	59.3				19
17			15.7	21.4	27.1	32.8	38.5	44.2	49.9	55.6	61.3	67.0	72.7			13
18			17.6	24.0	30.4	36.8	43.2	49.6	56.0	62.4	68.8	75.2	81.6			23
19			19.7	26.8	33.9	41.1	48.2	55.3	62.4	69.6	76.7	83.8	91.0	98.1		13
20				29.7	37.6	45.5	53.4	61.3	69.2	77.1	85.0	92.9	100.9	108.8		9
21				32.7	41.4	50.2	58.9	67.6	76.3	85.1	93.8	102.5	111.2	119.9	128.7	5
22				35.9	45.5	55.1	64.6	74.2	83.8	93.4	102.9	112.5	122.1	131.7	141.3	12
23				39.2	49.7	60.2	70.6	81.1	91.6	102.1	112.5	123.0	133.5	144.0	154.4	3
24				42.7	54.1	65.5	76.9	88.3	99.7	111.1	122.6	134.0	145.4	156.8	168.2	6
25					58.7	71.1	83.5	95.9	108.2	120.6	133.0	145.4	157.7	170.1	182.5	2
26					63.5	76.9	90.3	103.7	117.1	130.5	143.9	157.2	170.6	184.0	197.4	2
27					68.5	82.9	97.4	111.8	126.3	140.7	155.1	169.6	184.0	198.5	212.9	1
28					73.6	89.2	104.7	120.2	135.8	151.3	166.9	182.4	197.9	213.5	229.0	0
29					79.0	95.7	112.3	129.0	145.7	162.3	179.0	195.7	212.3	229.0	245.7	1
30						102.4	120.2	138.0	155.9	173.7	191.6	209.4	227.2	245.1	262.9	0
31						109.3	128.3	147.4	166.4	185.5	204.5	223.6	242.6	261.7	280.7	0
32						116.5	136.8	157.1	177.4	197.7	218.0	238.3	258.5	278.8	299.1	0
33						123.8	145.4	167.0	188.6	210.2	231.8	253.4	275.0	296.6	318.1	0
34						131.5	154.4	177.3	200.2	223.1	246.1	269.0	291.9	314.8	337.7	0
35							163.6	187.9	212.2	236.5	260.7	285.0	309.3	333.6	357.9	0
36							173.1	198.8	224.5	250.2	275.9	301.5	327.2	352.9	378.6	0
37							182.8	210.0	237.1	264.2	291.4	318.5	345.7	372.8	400.0	0
38							192.8	221.5	250.1	278.7	307.4	336.0	364.6	393.2	421.9	0
39							203.1	233.3	263.4	293.6	323.7	353.9	384.1	414.2	444.4	0
40								245.4	277.1	308.8	340.6	372.3	404.0	435.7	467.5	0
41								257.8	291.1	324.5	357.8	391.1	424.5	457.8	491.1	0
42								270.5	305.5	340.5	375.5	410.4	445.4	480.4	515.4	0
43								283.5	320.2	356.9	393.5	430.2	466.9	503.5	540.2	0
44								296.9	335.3	373.7	412.1	450.5	488.8	527.2	565.6	0
45									350.7	390.8	431.0	471.2	511.3	551.5	591.6	0
46									366.4	408.4	450.4	492.3	534.3	576.3	618.2	0
47									382.5	426.3	470.2	514.0	557.8	601.6	645.4	0
48									399.0	444.7	490.4	536.1	581.8	627.5	673.1	0
49									415.8	463.4	511.0	558.6	606.3	653.9	701.5	0
50									432.9	482.5	532.1	581.7	631.2	680.8	730.4	0
BASIS																

LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
5	.4	.6	.9	1.2	1.5											2
6	.6	1.1	1.7	2.2	2.8	3.3										4
7	.8	1.6	2.5	3.3	4.2	5.0	5.8									5
8	1.0	2.2	3.4	4.5	5.7	6.8	8.0	9.1								6
9	1.3	2.8	4.3	5.8	7.3	8.8	10.3	11.8	13.3							2
10		3.5	5.4	7.3	9.2	11.0	12.9	14.8	16.6							4
11		4.2	6.5	8.9	11.2	13.4	15.7	18.0	20.3	22.5						3
12		5.0	7.8	10.6	13.3	16.1	18.8	21.5	24.2	26.9						4
13		5.9	9.2	12.4	15.7	18.9	22.1	25.3	28.5	31.7	34.9					2
14		6.8	10.6	14.4	18.2	21.9	25.7	29.4	33.1	36.8	40.5					1
15			12.2	16.6	20.9	25.2	29.5	33.7	38.0	42.2	46.5	50.7				2
16			13.9	18.9	23.8	28.7	33.5	38.4	43.2	48.0	52.8	57.6				2
17			15.7	21.3	26.9	32.4	37.9	43.3	48.7	54.2	59.6	65.0	70.3			2
18			17.6	23.9	30.1	36.3	42.4	48.5	54.6	60.6	66.7	72.7	78.7			1
19			19.6	26.6	33.5	40.4	47.2	54.0	60.7	67.4	74.1	80.8	87.5	94.1		2
20				29.4	37.1	44.7	52.2	59.7	67.2	74.6	82.0	89.3	96.7	104.0		2
21				32.4	40.9	49.3	57.5	65.7	73.9	82.0	90.1	98.2	106.3	114.3	122.3	1
22				35.6	44.9	54.0	63.0	72.0	80.9	89.8	98.7	107.5	116.3	125.0	133.7	1
23				38.9	49.0	59.0	68.8	78.6	88.3	97.9	107.6	117.1	126.7	136.2	145.6	2
24				42.3	53.3	64.1	74.8	85.4	95.9	106.4	116.8	127.1	137.4	147.7	157.9	2
25					57.8	69.5	81.0	92.4	103.8	115.1	126.3	137.5	148.6	159.7	170.6	1
26					62.4	75.0	87.5	99.8	112.0	124.1	136.2	148.2	160.1	172.0	183.8	1
27					67.2	80.8	94.2	107.4	120.4	133.5	146.4	159.2	172.0	184.7	197.2	2
28					72.2	86.8	101.1	115.2	129.2	143.1	156.9	170.6	184.3	197.8	211.3	2
29					77.4	93.0	108.2	123.3	138.2	153.0	167.7	182.3	196.9	211.4	225.6	1
30						99.3	115.6	131.6	147.5	163.2	178.8	194.4	209.8	225.1	240.3	1
31						105.8	123.2	140.2	157.0	173.7	190.3	206.7	223.1	239.3	255.4	1
32						112.7	131.0	149.0	166.8	184.4	202.0	219.4	236.7	253.8	270.8	1
33						119.6	139.0	158.0	176.8	195.5	214.2	232.8	251.3	269.8	288.2	1
34						126.8	147.2	167.3	187.1	206.8	226.3	245.8	265.2	284.5	303.8	1
35							155.6	176.8	197.6	218.3	238.8	259.3	279.7	299.9	320.1	1
36							164.3	186.5	208.4	230.1	251.7	273.2	294.6	316.0	337.2	1
37							173.1	196.4	219.4	242.2	264.8	287.1	309.3	331.5	353.6	1
38							182.0	206.6	230.7	254.5	278.1	301.5	324.7	347.7	370.6	1
39							191.4	217.0	242.1	267.1	291.7	316.2	340.4	364.4	388.3	1
40								227.6	253.8	279.8	305.6	331.1	356.4	381.6	406.7	1
41								238.4	265.8	292.9	319.7	346.4	373.0	399.5	425.8	1
42								249.4	277.9	306.1	334.1	361.9	389.6	417.2	444.7	1
43								260.6	290.3	319.6	348.7	377.6	406.4	435.0	463.5	1
44								272.0	302.8	333.3	363.5	393.6	423.5	453.2	482.8	1
45									315.6	347.2	378.5	409.6	440.5	471.2	501.8	1
46									328.6	361.4	394.0	426.5	457.8	488.9	519.9	1
47									341.8	375.7	409.4	443.0	476.5	508.8	541.0	1
48									355.2	390.3	425.1	459.6	494.0	528.3	562.5	1
49									368.7	405.1	441.3	476.7	512.0	547.2	582.2	1
50									382.5	420.3	457.9	494.3	531.5	568.5	605.2	1

BASIC

NET CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES
BLACKJACK PINE
COCONINO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.4	.7	.9	1.2	1.5											15
6	.6	1.1	1.7	2.2	2.8	3.4										26
7	.8	1.6	2.5	3.3	4.2	5.0	5.9									34
8	1.0	2.2	3.4	4.5	5.7	6.9	8.0	9.2								34
9	1.3	2.8	4.3	5.9	7.4	8.9	10.4	11.9	13.4							24
10		3.5	5.4	7.3	9.2	11.1	13.0	14.9	16.8							34
11		4.2	6.6	8.9	11.2	13.6	15.9	18.2	20.5	22.8						17
12		5.0	7.8	10.6	13.4	16.2	19.0	21.8	24.5	27.3						26
13		5.9	9.2	12.5	15.8	19.1	22.4	25.7	28.9	32.1	35.3					11
14		6.8	10.7	14.5	18.4	22.2	26.0	29.8	33.6	37.3	41.1					16
15			12.3	16.7	21.1	25.5	29.9	34.3	38.6	42.9	47.2	51.4				11
16			13.9	19.0	24.0	29.0	34.1	39.0	44.0	48.9	53.7	58.5				10
17			15.7	21.4	27.1	32.8	38.5	44.1	49.7	55.2	60.6	66.0	71.2			5
18			17.6	24.0	30.4	36.8	43.1	49.5	55.7	61.9	68.0	73.9	79.8			6
19			19.6	26.8	33.9	41.0	48.1	55.1	62.1	68.9	75.7	82.3	88.8	95.2		8
20				29.7	37.6	45.4	53.3	61.1	68.8	76.4	83.8	91.1	98.2	105.3		4
21				32.7	41.4	50.1	58.7	67.3	75.8	84.2	92.3	100.3	108.1	115.8	123.5	3
22				35.9	45.4	55.0	64.5	73.9	83.2	92.3	101.2	110.0	118.5	126.8	135.1	7
23				39.2	49.7	60.1	70.4	80.7	90.9	100.8	110.6	120.0	129.2	138.3	147.3	1
24				42.7	54.1	65.4	76.7	87.9	98.9	109.7	120.3	130.5	140.4	150.2	159.9	4
25					58.7	71.0	83.2	95.3	107.3	119.0	130.3	141.3	152.0	162.5	172.9	2
26					63.4	76.7	90.0	103.1	116.0	128.6	140.8	152.6	164.1	175.3	186.4	1
27					68.4	82.8	97.0	111.1	125.0	138.6	151.7	164.3	176.5	188.5	200.3	1
28					73.6	89.0	104.3	119.5	134.4	148.9	162.9	176.4	189.4	202.1	214.7	0
29					78.9	95.4	111.9	128.1	144.1	159.6	174.5	188.9	202.7	216.1	229.4	2
30						102.1	119.7	137.1	154.1	170.6	186.5	201.7	216.4	230.6	244.6	0
31						109.0	127.8	146.3	164.4	182.0	198.9	215.0	230.4	245.4	260.2	0
32						116.1	136.1	155.8	175.1	193.7	211.6	228.6	244.9	260.7	276.2	0
33						123.5	144.7	165.7	186.1	205.8	224.7	242.6	259.7	276.3	292.6	0
34						131.1	153.6	175.8	197.4	218.3	238.2	257.0	275.0	292.3	309.4	0
35							162.7	186.2	209.1	231.1	252.0	271.8	290.6	308.7	326.5	0
36							172.1	196.9	221.0	244.2	266.2	287.0	306.6	325.5	344.1	0
37							181.7	207.9	233.3	257.7	280.8	302.5	323.0	342.6	362.0	0
38							191.7	219.2	245.9	271.5	295.7	318.4	339.7	360.2	380.3	0
39							201.8	230.8	258.9	285.7	311.0	334.6	356.8	378.0	398.9	0
40								242.7	272.1	300.2	326.7	351.2	374.3	396.3	417.9	0
41								254.8	285.7	315.1	342.6	368.2	392.1	414.9	437.2	0
42								267.3	299.6	330.3	359.0	385.6	410.3	433.9	456.9	0
43								280.0	313.8	345.8	375.7	403.2	428.8	453.2	477.0	0
44								293.1	328.3	361.7	392.7	421.3	447.7	472.8	497.4	0
45									343.2	377.9	410.1	439.7	467.0	492.8	518.2	0
46									358.3	394.5	427.9	458.4	486.6	513.2	539.2	0
47									373.8	411.4	446.0	477.5	506.5	533.9	560.7	0
48									389.6	428.6	464.4	497.0	526.8	554.9	582.5	0
49									405.7	446.1	483.2	516.8	547.4	576.3	604.6	0
50									422.1	464.0	502.3	536.9	568.4	598.0	627.0	0
BASIS TREES	1	27	63	89	60	37	19	7	1	2	0	0	0	0	0	

BLACKJACK PINE
TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.4	.7	.9	1.2	1.5											22
6	.6	1.1	1.7	2.2	2.8	3.4										33
7	.8	1.6	2.5	3.3	4.2	5.0	5.9									35
8	1.0	2.2	3.4	4.5	5.7	6.9	8.0	9.2								38
9	1.3	2.8	4.3	5.8	7.4	8.9	10.4	11.9	13.4							31
10		3.5	5.4	7.3	9.2	11.1	13.0	14.9	16.8							43
11		4.2	6.6	8.9	11.2	13.6	15.9	18.2	20.6	22.9						95
12		5.0	7.8	10.6	13.4	16.2	19.0	21.8	24.6	27.4						2[illegible]
13		5.9	9.2	12.5	15.8	19.1	22.4	25.7	29.0	32.2	35.5					23
14		6.8	10.7	14.5	18.3	22.2	26.0	29.8	33.6	37.5	41.3					1[illegible]
15			12.2	16.6	21.0	25.5	29.9	34.3	38.7	43.1	47.4	51.8				15
16			13.9	18.9	23.9	29.0	34.0	39.0	44.0	49.0	54.0	59.0				
17			15.7	21.4	27.0	32.7	38.3	44.0	49.6	55.3	60.9	66.6	72.2			10
18			17.6	23.9	30.3	36.6	43.0	49.3	55.6	61.9	68.2	74.5	80.8			12
19			19.6	26.6	33.7	40.8	47.8	54.8	61.9	68.9	75.9	82.9	89.9	96.9		7
20				29.5	37.3	45.1	52.9	60.7	68.4	76.2	83.9	91.6	99.3	107.1		4
21				32.4	41.0	49.6	58.2	66.7	75.3	83.8	92.3	100.7	109.2	117.6	126.1	3
22				35.5	45.0	54.4	63.7	73.1	82.4	91.7	100.9	110.2	119.4	128.6	137.8	1
23				38.8	49.0	59.3	69.5	79.6	89.8	99.9	109.9	120.0	130.0	139.9	149.9	1
24				42.1	53.3	64.4	75.4	86.4	97.4	108.3	119.2	130.1	140.9	151.6	162.4	1
25					57.7	69.7	81.6	93.5	105.3	117.1	128.8	140.5	152.1	163.7	175.3	
26					62.2	75.1	88.0	100.7	113.4	126.1	138.7	151.2	163.6	176.0	188.4	1
27					66.9	80.8	94.6	108.3	121.8	135.3	148.8	162.2	175.5	188.7	201.9	
28					71.8	86.6	101.3	115.9	130.9	144.9	159.3	173.5	187.6	201.7	215.7	1
29					76.8	92.6	108.3	123.9	139.3	154.7	169.9	185.1	[illegible]	[illegible]	229.9	
30						98.8	115.5	132.0	148.4	164.7	180.9	196.9	212.8	228.6	[illegible]	
31						105.1	122.8	140.4	157.8	175.0	192.1	209.1	225.9	[illegible]	259.2	
32						111.7	130.4	149.1	167.4	185.6	203.7	221.6	239.4	256.9	[illegible]	
33						118.4	138.2	157.8	177.2	196.4	215.5	234.3	253.0	271.5	289.8	
34						125.3	146.2	166.9	187.3	[illegible]	227.6	[illegible]	267.1	286.6	[illegible]	
35							154.4	176.1	197.6	218.9	239.9	[illegible]	[illegible]	[illegible]	[illegible]	
36							162.7	185.6	208.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
37							171.3	195.3	219.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
38							180.2	205.2	230.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
39							189.2	215.3	241.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
40								225.6	252.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
41								236.1	264.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
42								246.8	276.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
43								257.7	288.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
44								268.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
45									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
46									325.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
47									338.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
48									351.9	388.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
49									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
50									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES—UNFORKED TREES
BLACKJACK PINE
LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.5	1.0	1.6	2.1	2.7	3.3	3.8									23
8	.8	1.7	2.6	3.6	4.5	5.4	6.3	7.3								27
9	1.1	2.4	3.7	5.0	6.4	7.7	9.0	10.3	11.6							57
10		3.1	4.9	6.6	8.4	10.1	11.8	13.6	15.3							74
11		3.9	6.1	8.3	10.5	12.7	14.9	17.0	19.2	21.4						51
12		4.8	7.4	10.1	12.8	15.4	18.1	20.8	23.4	26.1						55
13		5.7	8.9	12.0	15.2	18.4	21.6	24.8	28.0	31.2	34.3					30
14		6.6	10.4	14.1	17.8	21.6	25.3	29.1	32.8	36.5	40.3					22
15			12.0	16.3	20.6	25.0	29.3	33.6	38.0	42.3	46.6	50.9				23
16			13.7	18.6	23.6	28.6	33.5	38.5	43.4	48.4	53.3	58.3				19
17			15.5	21.1	26.8	32.4	38.0	43.6	49.2	54.9	60.5	66.1	71.7			13
18			17.4	23.8	30.1	36.4	42.7	49.1	55.4	61.7	68.0	74.4	80.7			23
19			19.5	26.5	33.6	40.7	47.7	54.8	61.9	68.9	76.0	83.1	90.1	97.2		13
20				29.4	37.3	45.1	53.0	60.8	68.7	76.5	84.4	92.2	100.1	107.9		9
21				32.5	41.2	49.8	58.5	67.2	75.8	84.5	93.2	101.8	110.5	119.2	127.8	5
22				35.7	45.2	54.7	64.3	73.8	83.3	92.8	102.4	111.9	121.4	130.9	140.5	12
23				39.0	49.5	59.9	70.3	80.7	91.1	101.6	112.0	122.4	132.8	143.3	153.7	3
24				42.5	53.9	65.2	76.6	88.0	99.3	110.7	122.0	133.4	144.8	156.1	167.5	6
25					58.5	70.8	83.2	95.5	107.8	120.2	132.5	144.8	157.2	169.5	181.8	2
26					63.3	76.7	90.0	103.4	116.7	130.0	143.4	156.7	170.1	183.4	196.8	2
27					68.3	82.7	97.1	111.5	125.9	140.3	154.7	169.1	183.5	197.9	212.3	1
28					73.5	89.0	104.5	120.0	135.5	150.9	166.4	181.9	197.4	212.9	228.4	0
29					78.8	95.4	112.1	128.7	145.3	162.0	178.6	195.2	211.9	228.5	245.1	1
30						102.2	120.0	137.8	155.6	173.4	191.2	209.0	226.8	244.6	262.4	0
31						109.1	128.1	147.1	166.2	185.2	204.2	223.2	242.2	261.2	280.3	0
32						116.3	136.5	156.8	177.1	197.4	217.6	237.9	258.2	278.4	298.7	0
33						123.7	145.2	166.8	188.4	209.9	231.5	253.0	274.6	296.1	317.7	0
34						131.3	154.2	177.1	200.0	222.9	245.7	268.6	291.5	314.4	337.3	0
35							163.4	187.7	211.9	236.2	260.4	284.7	309.0	333.2	357.5	0
36							172.9	198.6	224.2	249.9	275.6	301.2	326.9	352.6	378.3	0
37							182.6	209.8	236.9	264.0	291.1	318.2	345.4	372.5	399.6	0
38							192.7	221.3	249.9	278.5	307.1	335.7	364.3	392.9	421.5	0
39							202.9	233.1	263.2	293.4	323.5	353.6	383.8	413.9	444.0	0
40								245.2	276.9	308.6	340.3	372.0	403.7	435.4	467.1	0
41								257.6	290.9	324.2	357.6	390.9	424.2	457.5	490.8	0
42								270.4	305.3	340.3	375.2	410.2	445.2	480.1	515.1	0
43								283.4	320.0	356.7	393.3	430.0	466.6	503.3	539.9	0
44								296.7	335.1	373.5	411.9	450.2	488.6	527.0	565.4	0
45									350.5	390.7	430.8	470.9	511.1	551.2	591.4	0
46									366.3	408.2	450.2	492.1	534.1	576.0	618.0	0
47									382.4	426.2	470.0	513.8	557.6	601.3	645.1	0
48									398.8	444.5	490.2	535.9	581.5	627.2	672.9	0
49									415.6	463.2	510.8	558.4	606.0	653.6	701.2	0
50									432.8	482.3	531.9	581.5	631.0	680.6	730.2	0
BASIS TREES	1	49	119	191	165	79	44	17	4	2	1	0	0	0	0	

NET CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES

NET CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES
BLACKJACK PINE
LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREE
7	.5	1.0	1.6	2.1	2.7	3.2	3.8									
8	.8	1.7	2.6	3.5	4.5	5.4	6.3	7.2								
9	1.1	2.4	3.7	5.0	6.3	7.6	8.9	10.2	11.5							
10		3.1	4.9	6.6	8.3	10.0	11.7	13.4	15.1							
11		3.9	6.1	8.3	10.4	12.6	14.7	16.8	18.9	21.1						
12		4.8	7.4	10.1	12.7	15.3	17.9	20.5	23.1	25.7						
13		5.7	8.8	12.0	15.1	18.2	21.3	24.4	27.5	30.6	33.6					
14		6.6	10.3	14.0	17.7	21.3	25.0	28.6	32.2	35.8	39.4					
15			11.9	16.2	20.4	24.7	28.8	33.0	37.2	41.3	45.4	49.6				
16			13.6	18.5	23.4	28.2	33.0	37.7	42.4	47.2	51.9	56.6				
17			15.4	21.0	26.5	31.9	37.3	42.7	48.0	53.4	58.7	64.0	69.3			
18			17.4	23.6	29.7	35.9	41.9	47.9	53.9	59.9	65.9	71.8	77.7			
19			19.4	26.3	33.2	40.0	46.7	53.4	60.1	66.7	73.4	80.0	86.5	93.1		
20				29.2	36.8	44.3	51.8	59.2	66.6	73.9	81.2	88.5	95.8	103.0		
21				32.2	40.6	48.9	57.1	65.2	73.3	81.4	89.4	97.4	105.4	113.4	121.4	
22				35.4	44.6	53.7	62.6	71.5	80.4	89.2	98.0	106.7	115.4	124.0	132.6	
23				38.7	48.7	58.6	68.4	78.1	87.7	97.3	106.8	116.3	125.8	135.2	144.5	
24				42.1	53.0	63.8	74.4	84.9	95.4	105.7	116.1	126.3	136.5	146.7	156.8	
25					57.5	69.2	80.6	92.0	103.3	114.4	125.6	136.7	147.7	158.6	169.5	
26					62.2	74.7	87.1	99.3	111.4	123.4	135.4	147.3	159.1	170.9	182.6	
27					67.1	80.5	93.8	106.9	119.9	132.8	145.6	158.3	171.0	183.5	196.1	
28					72.2	86.5	100.7	114.7	128.6	142.4	156.1	169.7	183.2	196.6	209.9	
29					77.2	92.7	107.8	122.8	137.6	152.2	166.8	181.2	195.7	210.1	224.3	
30						99.0	115.2	131.1	146.8	162.4	177.9	193.3	208.6	223.7	238.8	
31						105.6	122.7	139.6	156.3	172.9	189.3	205.6	221.8	237.8		
32						112.3	130.5	148.4	166.1	183.6	201.0	218.2	235.2	252.1	268.8	
33						119.3	138.5	157.4	176.2	194.9	213.4	231.8	250.0	268.0	285.8	
34						126.4	146.7	166.6	186.4	206.1	225.7	245.1	264.3	283.4	302.3	
35							155.1	176.1	196.9	217.6	238.1	258.5	278.7	298.8	318.7	
36							163.7	185.7	207.6	229.4	251.0	272.4	293.6	314.7	335.6	
37							172.5	195.6	218.6	241.4	264.2	285.8	307.3	328.6	349.8	
38							181.5	205.7	229.8	253.9	277.8	301.5	324.1	346.5	368.7	
39							190.7	216.0	241.2	266.4	291.4	316.2	340.0	363.6	386.9	
40								226.5	252.8	279.2	305.4	331.4	356.2	380.9	405.4	
41								237.2	264.6	292.2	319.6	346.8	372.8	398.6	424.2	
42								248.2	276.8	305.6	334.2	362.6	389.8	416.8	443.6	
43								259.3	288.9	318.9	348.7	378.3	406.7	434.9	462.8	
44								270.7	301.1	332.3	363.3	394.1	423.7	453.1	482.2	
45									313.8	345.9	378.0	410.0	440.8	471.4	501.8	
46									326.6	359.7	392.8	425.8	457.8	489.6	521.2	
47									339.5	373.7	407.8	442.0	475.1	508.0	540.7	
48									352.6	387.8	423.0	458.3	492.6	526.7	560.5	
49									365.8	402.1	438.4	474.7	510.2	545.6	580.7	
50									379.2	416.6	454.0	491.3	528.0	564.6	600.9	

NET CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES
BLACKJACK PINE
COCONINO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.5	1.0	1.6	2.1	2.7	3.2	3.8									34
8	.8	1.7	2.6	3.6	4.5	5.4	6.3	7.3								34
9	1.1	2.4	3.7	5.0	6.4	7.7	9.0	10.3	11.6							[illegible]
10		3.1	4.9	6.6	8.3	10.1	11.8	13.5	15.3							34
11		3.9	6.1	8.3	10.5	12.7	14.8	17.0	19.2	21.3						17
12		4.8	7.4	10.1	12.8	15.4	18.1	20.7	23.4	26.0						[illegible]
13		5.7	8.8	12.0	15.2	18.4	21.6	24.7	27.9	31.0	34.1					11
14		6.6	10.4	14.1	17.8	21.6	25.3	29.0	32.7	36.3	39.9					14
15			12.0	16.3	20.6	24.9	29.2	33.5	37.8	42.0	46.1	50.2				11
16			13.7	18.6	23.6	28.5	33.5	38.4	43.2	48.0	52.8	57.4				10
17			15.5	21.1	26.7	32.3	37.9	43.5	49.0	54.4	59.8	65.0	70.2			5
18			17.4	23.7	30.1	36.4	42.6	48.9	55.1	61.2	67.2	73.0	78.8			6
19			19.4	26.5	33.6	40.6	47.6	54.6	61.5	68.3	74.9	81.5	87.9	94.2		[illegible]
20				29.4	37.2	45.1	52.8	60.6	68.2	75.7	83.1	90.3	97.4	104.3		4
21				32.5	41.1	49.7	58.3	66.9	75.3	83.6	91.7	99.6	107.3	114.9	122.5	3
22				35.7	45.2	54.7	64.1	73.4	82.7	91.8	100.6	109.2	117.7	125.9	134.1	7
23				39.0	49.4	59.8	70.1	80.3	90.4	100.3	109.9	119.3	128.4	137.4	146.3	1
24				42.5	53.8	65.1	76.4	87.5	98.5	109.2	119.7	129.8	139.6	149.3	158.8	4
25					58.4	70.7	82.9	95.0	106.9	118.5	129.8	140.7	151.2	161.6	171.8	[illegible]
26					63.2	76.5	89.7	102.7	115.6	128.1	140.2	151.9	163.3	174.3	185.3	1
27					68.2	82.5	96.7	110.8	124.6	138.1	151.1	163.6	175.7	187.5	199.2	1
28					73.4	88.8	104.0	119.2	134.0	148.4	162.3	175.7	188.5	201.1	213.5	0
29					78.7	95.2	111.6	127.8	143.7	159.1	173.9	188.1	201.8	215.1	228.2	2
30						101.9	119.4	136.8	153.7	170.1	185.9	201.0	215.4	229.4	243.3	0
31						108.8	127.5	146.0	164.1	181.5	198.3	214.2	229.4	244.2	258.8	0
32						116.0	135.9	155.5	174.7	193.3	211.0	227.8	243.9	259.4	274.7	0
33						123.3	144.5	165.4	185.7	205.4	224.1	241.8	258.7	274.9	291.0	0
34						130.9	153.4	175.5	197.0	217.8	237.5	256.1	273.8	290.9	307.6	0
35							162.5	185.9	208.7	230.6	251.3	270.9	289.4	307.2	324.7	0
36							171.9	196.6	220.6	243.7	265.5	286.0	305.3	323.8	342.1	0
37							181.5	207.6	232.9	257.2	280.0	301.4	321.6	340.9	359.8	0
38							191.4	218.9	245.5	271.0	294.9	317.3	338.2	358.3	378.0	0
39							201.6	230.5	258.5	285.1	310.2	333.4	355.2	376.1	396.5	0
40								242.4	271.7	299.6	325.8	350.0	372.6	394.2	415.3	0
41								254.5	285.3	314.5	341.7	366.9	390.3	412.6	434.5	0
42								267.0	299.1	329.6	358.0	384.2	408.4	431.5	454.0	0
43								279.7	313.3	345.1	374.6	401.8	426.8	450.6	473.9	0
44								292.8	327.8	361.0	391.6	419.7	445.6	470.1	494.1	0
45									342.7	377.1	409.0	438.0	464.7	490.0	514.7	0
46									357.8	393.6	426.7	456.7	484.2	510.2	535.6	0
47									373.3	410.5	444.7	475.7	504.0	530.7	556.9	0
48									389.0	427.7	463.0	495.0	524.2	551.6	578.5	0
49									405.1	445.2	481.8	514.7	544.7	572.8	600.4	0
50									421.5	463.0	500.8	534.8	565.5	594.4	622.7	0
BASIS TREES	1	27	63	89	60	37	19	7	1	2	0	0	0	0	0	

BLACKJACK PINE
TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.5	1.0	1.6	2.1	2.7	3.2	3.8									9
8	.8	1.7	2.6	3.6	4.5	5.4	6.3	7.3								30
9	1.1	2.4	3.7	5.0	6.4	7.7	9.0	10.3	11.6							31
10		3.1	4.9	6.6	8.3	10.1	11.8	13.6	15.3							43
11		3.9	6.1	8.3	10.5	12.7	14.8	17.0	19.2	21.4						35
12		4.8	7.4	10.1	12.8	15.4	18.1	20.7	23.4	26.1						31
13		5.7	8.8	12.0	15.2	18.4	21.6	24.7	27.9	31.1	34.3					21
14		6.6	10.3	14.1	17.8	21.5	25.3	29.0	32.7	36.4	40.1					15
15			12.0	16.3	20.6	24.9	29.2	33.5	37.8	42.1	46.4	50.7				14
16			13.7	18.6	23.5	28.5	33.4	38.3	43.2	48.1	53.1	58.0				8
17			15.5	21.0	26.6	32.2	37.8	43.4	48.9	54.5	60.1	65.6	71.2			10
18			17.4	23.6	29.9	36.2	42.5	48.7	55.0	61.2	67.4	73.7	79.9			12
19			19.4	26.4	33.4	40.4	47.3	54.3	61.3	68.2	75.1	82.1	89.0	95.9		7
20				29.2	37.0	44.7	52.4	60.2	67.9	75.5	83.2	90.9	98.5	106.1		4
21				32.2	40.8	49.3	57.8	66.3	74.7	83.2	91.6	100.0	108.4	116.8	125.1	3
22				35.3	44.7	54.0	63.3	72.6	81.9	91.1	100.3	109.5	118.6	127.8	136.9	1
23				38.6	48.8	59.0	69.1	79.2	89.3	99.3	109.3	119.3	129.3	139.1	149.1	2
24				41.9	53.0	64.1	75.1	86.0	96.9	107.8	118.6	129.4	140.1	150.8	161.4	2
25					57.4	69.4	81.2	93.0	104.8	116.5	128.2	139.7	151.3	162.8	174.2	
26					62.0	74.8	87.6	100.3	112.9	125.5	138.0	150.4	162.8	175.1	187.4	1
27					66.7	80.5	94.2	107.8	121.3	134.7	148.1	161.4	174.6	187.7	200.8	
28					71.5	86.3	100.9	115.5	129.9	144.2	158.5	172.6	186.7	200.7	214.5	
29					76.5	92.3	107.9	123.4	138.8	154.1	169.1	184.0	199.1	213.9	228.6	
30						98.4	115.1	131.5	147.8	164.0	180.1	196.0	211.8	227.4	243.0	
31						104.8	122.4	139.9	157.1	174.3	191.4	208.3	225.1	241.8	258.4	
32						111.3	130.0	148.4	166.7	184.8	202.8	220.7	238.4	256.0	273.4	
33						118.0	137.7	157.2	176.5	195.5	214.4	233.1	251.6	269.9	288.1	
34						124.8	145.6	166.2	186.5	206.5	226.4	246.0	265.5	284.8	304.0	
35							153.8	175.4	196.7	217.8	238.6	259.2	279.6	299.8	319.7	
36							162.1	184.8	207.3	229.3	251.2	272.7	294.1	315.2	336.1	
37							170.6	194.4	217.9	241.1	264.0	286.5	308.8	330.9	352.8	
38							179.3	204.2	228.8	253.1	277.1	300.6	324.0	346.9	369.7	
39							188.1	214.1	240.1	265.8	290.3	314.9	339.2	363.2	387.0	
40								224.5	251.3	277.7	303.8	329.5	354.8	379.9	404.8	
41								234.9	262.9	290.4	317.6	344.4	370.9	397.1	423.1	
42								245.5	274.7	303.4	331.6	359.4	386.9	414.1	441.1	
43								256.3	286.8	316.5	345.9	374.8	403.5	431.9	460.1	
44								267.3	298.9	329.8	360.4	390.6	420.5	450.2	479.6	
45								278.5	311.2	343.4	375.1	406.5	437.7	468.6	499.3	
46								289.8	323.8	357.3	390.4	423.0	455.4	487.5	519.4	
47								301.3	336.5	371.4	405.7	439.6	473.2	506.6	539.7	
48								313.0	349.6	385.8	421.3	456.6	491.4	526.0	560.4	
49								324.8	362.8	400.4	437.2	473.8	510.0	545.9	581.6	
50								336.8	376.2	415.2	453.3	491.2	528.8	566.1	603.1	

GROSS INTERNATIONAL BOARD FOOT VOLUME T 6 INCH TOP DIB-UNMARKED TREES
BLACKJACK PINE
LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.6	1.3	2.0	2.6	3.3	4.0	4.7									73
8	1.9	4.2	6.4	8.6	10.9	13.1	15.4	17.6								77
9	3.5	7.8	12.1	16.4	20.7	25.0	29.3	33.6	37.9							57
10		12.1	18.8	25.6	32.3	39.0	45.7	52.4	59.1							74
11		17.0	26.4	35.8	45.3	54.7	64.2	73.6	83.1	92.5						71
12		22.3	34.7	47.2	59.6	72.1	84.6	97.0	109.5	121.9						65
13		28.0	43.8	59.5	75.3	91.0	106.8	122.6	138.3	154.1	169.8					33
14		34.2	53.6	72.9	92.2	111.5	130.9	150.2	169.5	188.8	208.2					30
15			64.1	87.2	110.4	133.6	156.7	179.9	203.1	226.3	249.4	272.5				23
16			75.3	102.6	129.9	157.1	184.4	211.7	238.9	266.2	293.5	320.7				19
17			87.3	118.9	150.6	182.2	213.9	245.5	277.1	308.8	340.4	372.1	403.7			13
18			100.0	136.3	172.5	208.8	245.1	281.4	317.7	354.0	390.2	426.5	462.8			23
19			113.4	154.6	195.8	237.0	278.2	319.4	360.6	401.8	442.9	484.1	525.3	566.5		1
20				173.9	220.3	266.7	313.0	359.4	405.8	452.1	498.5	544.9	591.3	637.6		3
21				194.2	246.1	297.9	349.7	401.5	453.3	505.2	557.0	608.8	660.6	712.4	764.2	1
22				215.6	273.1	330.6	388.2	445.7	503.2	560.8	618.3	675.8	733.4	790.9	848.4	10
23				237.9	301.4	364.9	428.5	492.0	555.5	619.0	682.5	746.0	809.6	873.1	936.6	3
24				261.2	331.0	400.8	470.5	540.3	610.1	679.9	749.6	819.4	889.2	958.9	1028.7	5
25					361.9	438.2	514.4	590.7	667.0	743.3	819.6	895.9	972.2	1048.5	1124.8	2
26					394.0	477.1	560.2	643.3	726.3	809.4	892.5	975.6	1058.7	1141.8	1224.9	2
27					427.4	517.6	607.7	697.9	788.0	878.2	968.3	1058.5	1148.6	1238.8	1328.9	1
28					462.1	559.6	657.1	754.5	852.0	949.5	1047.0	1144.5	1242.0	1339.5	1437.0	0
29					498.0	603.1	708.2	813.3	918.4	1023.5	1128.6	1233.7	1338.8	1443.9	1549.0	1
30						648.2	761.2	874.2	987.2	1100.1	1213.1	1326.1	1439.0	1552.0	1665.0	0
31						694.9	816.0	937.1	1058.3	1179.4	1300.5	1421.6	1542.7	1663.8	1784.9	0
32						743.1	872.7	1002.2	1131.7	1261.2	1390.8	1520.3	1649.8	1779.4	1908.9	0
33						792.9	931.1	1069.3	1207.5	1345.8	1484.0	1622.2	1760.4	1898.6	2036.9	0
34						844.2	991.4	1138.6	1285.7	1432.9	1580.1	1727.3	1874.4	2021.6	2168.8	0
35							1053.5	1209.9	1366.3	1522.7	1679.1	1835.5	1991.9	2148.3	2304.7	0
36							1117.4	1283.3	1449.2	1615.1	1781.0	1946.9	2112.8	2278.7	2444.6	0
37							1183.1	1358.8	1534.5	1710.2	1885.8	2061.5	2237.2	2412.9	2588.5	0
38							1250.7	1436.4	1622.1	1807.9	1993.6	2179.3	2365.0	2550.7	2736.4	0
39							1320.1	1516.1	1712.1	1908.2	2104.2	2300.2	2496.3	2692.3	2888.3	0
40								1597.9	1804.5	2011.1	2217.8	2424.4	2631.0	2837.6	3044.2	0
41								1681.8	1899.3	2116.7	2334.2	2551.7	2769.2	2986.6	3204.1	0
42								1767.8	1996.4	2225.0	2453.6	2682.2	2910.8	3139.4	3368.0	0
43								1855.9	2095.9	2335.9	2575.9	2815.9	3055.9	3295.9	3535.9	0
44								1946.1	2197.7	2449.4	2701.1	2952.7	3204.4	3456.1	3707.7	0
45									2301.9	2565.6	2829.2	3092.8	3356.4	3620.0	3883.6	0
46									2408.5	2684.3	2960.2	3236.0	3511.8	3787.6	4063.5	0
47									2517.5	2805.8	3094.1	3382.4	3670.7	3959.0	4247.3	0
48									2628.8	2929.9	3230.9	3532.0	3833.0	4134.1	4435.2	0
49									2742.5	3056.6	3370.7	3684.8	3998.8	4312.9	4627.0	0
50									2858.6	3185.9	3513.3	3840.7	4168.1	4495.5	4822.9	0
BASIS TREES	0	24	98	180	164	79	44	17	4	2	1	0	0	0	0	

BLACKJACK PINE
LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.5	1.1	1.7	2.3	2.9	3.6	4.2									
8	1.7	3.7	5.7	7.6	9.7	11.7	13.9	16.1								
9	3.2	7.0	10.7	14.5	18.4	22.4	26.5	30.7	35.0							
10		10.8	16.7	22.6	28.6	34.9	41.3	47.8	54.6							
11		15.0	23.3	31.7	40.2	48.9	57.9	67.2	76.6	86.3						
12		19.7	30.7	41.7	52.9	64.5	76.3	88.5	101.0	113.8						
13		24.8	38.7	52.6	66.8	81.4	96.4	111.9	127.7	143.7	160.0					
14		30.4	47.3	64.4	81.8	99.7	118.1	137.1	156.4	176.2	196.1					
15			56.6	77.1	98.0	119.4	141.5	164.2	187.4	211.0	234.9	259.0				
16			66.5	90.7	115.2	140.5	166.5	193.2	220.5	248.3	276.5	304.8				
17			77.1	105.1	133.6	162.9	193.1	224.1	255.8	288.0	320.7	353.6	386.7			
18			88.3	120.4	153.1	186.7	221.3	256.8	293.2	330.2	367.6	405.4	443.3			
19			100.2	136.6	173.7	211.8	251.1	291.5	333.8	374.8	417.3	460.1	503.0	546.2		
20				153.7	195.5	238.4	282.6	328.0	374.5	421.8	469.6	517.9	566.3	614.8		
21				171.6	218.3	266.3	315.7	366.4	418.4	471.2	524.7	578.6	632.7	686.9	741.1	
22				190.5	242.3	295.6	350.4	406.8	464.4	523.1	582.5	642.3	702.4	762.6	822.8	
23				210.2	267.4	326.2	386.8	449.0	512.7	577.4	643.0	709.1	775.4	841.8	908.3	
24				230.8	293.7	358.3	424.8	493.1	563.1	634.2	706.2	778.8	851.7	924.6	997.6	
25					321.1	391.7	464.4	539.1	615.6	693.4	772.2	851.5	931.2	1011.1	1090.8	
26					349.5	426.5	505.7	587.1	670.3	755.1	840.8	927.3	1014.2	1101.3	1187.8	
27					379.2	462.7	548.6	636.9	727.3	819.2	912.3	1006.1	1100.0	1194.5	1288.7	
28					410.0	500.2	593.1	688.6	786.3	885.8	986.4	1087.8	1189.6	1291.6	1393.5	
29					441.9	539.0	639.3	742.3	847.6	954.8	1063.2	1172.4	1282.1	1391.7	1501.2	
30						579.5	687.2	797.8	911.0	1026.2	1142.8	1260.3	1378.2	1496.5	1614.6	
31						621.2	736.6	855.3	976.7	1100.2	1225.2	1351.1	1477.6	1604.1	1730.9	
32						664.3	787.8	914.6	1044.5	1176.6	1310.0	1444.3	1580.0	1715.7	1851.4	
33						708.8	840.5	975.9	1114.4	1255.4	1398.0	1541.8	1686.1	1830.7	1975.4	
34						754.7	894.4	1039.1	1186.6	1336.7	1488.5	1641.2	1794.4	1948.2	2101.7	
35							951.0	1104.2	1260.9	1421.4	1581.9	1744.5	1907.9	2071.5	2235.0	
36							1008.7	1171.2	1337.5	1506.6	1677.9	1850.4	2024.1	2198.1	2372.2	
37							1068.0	1240.1	1416.2	1595.3	1776.6	1959.2	2143.2	2327.6	2512.2	
38							1129.2	1311.9	1497.1	1686.4	1878.1	2071.1	2265.4	2459.5	2654.1	
39							1191.7	1384.7	1580.1	1780.1	1982.4	2186.1	2391.0	2596.0	2801.1	
40								1458.3	1665.4	1876.1	2089.3	2304.0	2520.1	2736.4	2952.9	
41								1534.9	1752.8	1974.6	2199.1	2425.2	2652.1	2879.2	3106.4	
42								1613.4	1842.9	2075.6	2311.5	2549.3	2788.0	3026.9	3265.9	
43								1693.8	1934.3	2179.1	2426.7	2676.2	2926.9	3178.0	3428.9	
44								1776.1	2028.3	2285.0	2544.7	2806.4	3069.1	3332.0	3594.8	
45									2124.4	2393.3	2665.1	2939.1	3214.1	3489.1	3764.0	
46									2222.8	2504.1	2788.8	3075.6	3363.5	3651.5	3939.4	
47									2323.4	2617.4	2914.9	3214.8	3516.8	3818.6	4120.2	
48									2426.1	2733.1	3044.8	3356.9	3672.9	3988.6	4304.1	
49									2531.1	2851.1	3176.5	3501.1	3831.5	4161.7	4491.7	
50									2638.2	2971.1	3309.9	3648.2	3992.3	4336.2	4680.0	

NET INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB
BLACKJACK PINE
COCONINO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	TREES
7	.6	1.3	1.9	2.6	3.3	4.0	4.6									27
8	1.9	4.1	6.3	8.6	10.8	13.0	15.2	17.4								34
9	3.5	7.8	12.0	16.2	20.5	24.7	29.0	33.2	37.4							28
10		12.0	18.6	25.2	31.9	38.4	45.0	51.6	58.2							34
11		16.8	26.1	35.4	44.6	53.9	63.1	72.3	81.5	90.7						17
12		22.0	34.3	46.5	58.6	70.8	82.9	94.9	107.0	119.0						26
13		27.7	43.1	58.6	73.9	89.2	104.3	119.5	134.6	149.8	165.0					11
14		33.8	52.7	71.6	90.3	108.9	127.4	145.8	164.2	182.7	201.3					17
15			63.0	85.5	107.8	130.0	152.0	173.8	195.8	217.8	240.2	262.8				10
16			74.0	100.4	126.5	152.4	178.0	203.5	229.2	255.1	281.4	308.3				10
17			85.6	116.1	146.2	176.0	205.4	234.8	264.4	294.5	325.2	356.6	388.6			5
18			97.9	132.7	167.0	200.8	234.3	267.7	301.5	336.1	371.6	407.8	444.7			6
19			110.9	150.2	188.8	226.8	264.4	302.1	340.5	379.9	420.5	462.0	504.2	546.8		3
20				168.6	211.7	253.9	295.9	338.1	381.4	426.1	472.1	519.2	566.9	615.1		4
21				187.7	235.4	282.2	328.6	375.7	424.2	474.5	526.4	579.4	633.0	687.0	741.1	3
22				207.7	260.1	311.5	362.6	414.9	469.1	525.4	583.4	642.6	702.4	762.5	822.6	7
23				228.5	285.7	341.8	397.9	455.7	516.0	578.7	643.2	708.8	775.0	841.5	908.0	1
24				250.0	312.2	373.1	434.5	498.2	564.9	634.4	705.7	778.1	851.0	924.2	997.2	4
25					339.5	405.4	472.4	542.4	616.1	692.6	771.0	850.4	930.3	1010.4	1090.4	2
26					367.6	438.8	511.7	588.5	669.4	753.3	839.1	925.8	1013.0	1100.2	1187.3	1
27					396.5	473.1	552.4	636.4	724.8	816.5	909.9	1004.2	1098.9	1193.6	1288.1	1
28					426.2	508.5	594.5	686.1	782.5	882.1	983.5	1085.6	1188.1	1290.6	1392.8	0
29					456.6	545.0	638.2	737.8	842.4	950.3	1059.8	1170.1	1280.6	1391.1	1501.4	2
30						582.5	683.4	791.3	904.6	1020.9	1138.9	1257.6	1376.5	1495.3	1613.8	0
31						621.2	730.1	846.8	968.9	1094.1	1220.8	1348.1	1475.6	1603.0	1730.1	0
32						661.0	778.4	904.2	1035.5	1169.7	1305.4	1441.6	1578.0	1714.3	1850.2	0
33						702.0	828.4	963.6	1104.2	1247.8	1392.7	1538.2	1683.8	1829.2	1974.2	0
34						744.3	880.0	1024.9	1175.2	1328.4	1482.8	1637.8	1792.8	1947.6	2102.1	0
35							933.3	1088.1	1248.4	1411.4	1575.6	1740.4	1905.1	2069.7	2233.9	0
36							988.2	1153.3	1323.8	1496.9	1671.2	1846.0	2020.8	2195.3	2369.5	0
37							1044.8	1220.5	1401.4	1584.9	1769.5	1954.6	2139.7	2324.6	2509.0	0
38							1103.1	1289.6	1481.2	1675.3	1870.6	2066.3	2262.0	2457.4	2652.2	0
39							1163.0	1360.6	1563.1	1768.2	1974.3	2180.9	2387.5	2593.8	2799.6	0
40								1433.5	1647.3	1863.5	2080.9	2298.6	2516.4	2733.8	2950.6	0
41								1508.3	1733.6	1961.3	2190.1	2419.3	2648.5	2877.3	3105.6	0
42								1585.1	1822.1	2061.5	2302.1	2543.1	2784.0	3024.5	3264.5	0
43								1663.8	1912.8	2164.2	2416.8	2669.8	2922.7	3175.2	3427.2	0
44								1744.4	2005.7	2269.4	2534.3	2799.6	3064.8	3329.6	3593.8	0
45									2100.7	2377.0	2654.4	2932.3	3210.1	3487.5	3764.2	0
46									2197.9	2487.0	2777.4	3068.1	3358.8	3649.0	3938.5	0
47									2297.3	2599.5	2903.0	3206.9	3510.8	3814.1	4116.7	0
48									2398.8	2714.5	3031.4	3348.8	3666.0	3982.8	4298.8	0
49									2502.5	2831.8	3162.5	3493.6	3824.6	4155.1	4484.8	0
50									2608.4	2951.7	3296.3	3641.5	3986.5	4330.9	4674.6	0
BASIS TREES	0	11	46	78	59	37	19	7	1	2	0	0	0	0	0	

TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	RACTE TREE
7	.6	1.3	1.9	2.6	3.2	3.8	4.4									
8	1.9	4.1	6.3	8.5	10.6	12.6	14.5	16.5								
9	3.5	7.8	12.0	16.1	20.1	23.9	27.7	31.5	35.4							
10		12.0	18.6	25.0	31.3	37.3	43.2	49.1	55.2							
11		16.8	26.0	35.1	43.9	52.3	60.6	68.9	77.6	86.7						
12		22.1	34.3	46.2	57.8	69.0	79.9	90.8	102.3	114.3						
13		27.8	43.2	58.3	73.0	87.1	100.9	114.7	129.2	144.4	160.2					
14		34.0	52.8	71.4	89.4	106.7	123.6	140.5	158.2	177.0	196.3					
15			63.2	85.4	107.0	127.8	148.0	168.4	189.7	212.3	235.2	259.				
16			74.3	100.5	125.8	150.2	174.2	198.2	223.2	249.4	276.8	304.8				
17			86.1	116.5	145.9	174.3	202.0	229.9	258.9	289.3	321.1	353.6	386.5			
18			98.6	133.4	167.3	199.8	231.5	263.5	296.7	331.7	368.1	405.3	443.1			
19			111.9	151.4	189.7	226.7	262.7	299.0	336.8	376.5	417.8	460.1	503.9	546.		
20				170.3	213.5	255.1	295.7	336.5	379.0	423.7	470.3	517.8	566.1	614.6		
21				190.1	238.4	284.9	330.3	375.9	423.4	473.4	525.4	578.5	632.5	686.6	741.9	
22				211.1	264.6	316.3	366.6	417.3	470.0	525.5	583.2	642.3	702.1	762.3	823.5	
23				233.0	293.1	349.1	404.7	460.6	518.8	580.1	643.7	709.3	775.1	841.1	908.	
24				255.8	320.7	383.4	444.4	505.9	569.8	637.1	707.0	778.7	851.	924.3	997.7	
25					350.6	419.1	485.9	553.1	623.0	696.5	773.0	851.4	930.8	1011.6	1093.	
26					381.8	456.4	529.1	602.3	678.4	758.5	841.8	927.	1013.6	1101.5	1189.5	
27					414.1	495.1	574.0	653.4	736.2	822.9	913.7	1005.9	1099.7	1194.7	1288.	
28					447.7	535.2	620.6	706.5	795.8	889.7	987.5	1087.7	1189.1	1291.	1394.	
29					482.6	576.9	668.9	761.9	858.8	959.2	1064.4	1172.4	1281.8	1391.6	1501.6	
30					518.7	619.7	718.7	818.7	922.6	1030.9	1144.1	1260.	1377.8	1495.9	1614.7	
31					556.1	664.7	770.7	877.4	988.4	1105.1	1226.6	1351.7	1477.	1604.8	1732.4	
32					594.7	710.9	824.0	938.2	1057.6	1181.8	1311.7	1444.8	1579.6	1715.5	1852.5	
33					634.5	758.4	879.4	1001.2	1127.9	1261.1	1399.6	1541.6	1685.4	1830.	1975.6	
34					675.5	807.5	936.4	1066.	1200.	1340.7	1487.3	1638.3	1790.6	1945.2	2100.5	
35							995.	1132.8	1276.	1424.8	1581.6	1742.3	1905.	2069.	2234.	
36							1055.4	1201.5	1353.4	1511.2	1677.2	1847.5	2020.8	2195.	2370.9	
37							1117.5	1272.2	1433.1	1600.5	1775.6	1959.1	2141.9	2325.6	2509.	
38							1181.7	1344.9	1515.3	1692.4	1878.2	2071.	2264.6	2458.5	2652.8	
39							1246.8	1419.5	1599.2	1788.1	1984.6	2188.	2392.9	2597.9	2803.	
40								1496.	1686.5	1888.5	2097.3	2312.9	2529.	2745.9	2963.	
41								1574.6	1774.5	1988.5	2208.3	2435.	2663.5	2892.8	3122.	
42								1655.1	1865.4	2090.4	2321.6	2559.3	2798.9	3040.3	3282.1	
43								1737.6	1958.4	2194.8	2437.2	2687.1	2939.8	3193.8	3448.5	
44								1822.1	2053.7	2301.5	2555.8	2817.5	3082.1	3348.2	3615.1	
45									2151.5	2410.8	2676.1	2950.6	3227.9	3505.9	3784.8	
46									2251.1	2522.8	2798.9	3086.4	3376.4	3667.2	3958.9	
47									2352.5	2636.5	2924.5	3225.1	3528.6	3832.8	4137.8	
48									2455.4	2752.0	3052.8	3366.6	3682.5	3999.8	4318.1	
49									2561.5	2869.4	3183.7	3510.8	3839.9	4170.7	4502.4	
50									2669.9	2989.4	3317.5	3658.5	4000.8	4345.6	4691.5	

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNBORKED TREES
BLACKJACK PINE
LINCOLN-COCONINO-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.3	.7	1.1	1.5	1.9	2.2	2.6									0
8	1.2	2.7	4.2	5.6	7.1	8.5	10.0	11.5								0
9	2.5	5.6	8.6	11.7	14.8	17.8	20.9	23.9	27.0							31
10		9.2	14.2	19.3	24.4	29.5	34.5	39.6	44.7							74
11		13.4	20.8	28.3	35.7	43.2	50.6	58.1	65.5	73.0						51
12		18.1	28.3	38.4	48.6	58.7	68.9	79.0	89.2	99.3						55
13		23.4	36.5	49.7	62.8	76.0	89.1	102.3	115.4	128.6	141.7					30
14		29.1	45.6	62.0	78.4	94.9	111.3	127.7	144.2	160.6	177.0					29
15			55.3	75.3	95.3	115.3	135.3	155.3	175.3	195.3	215.3	235.3				23
16			65.9	89.7	113.5	137.4	161.2	185.1	208.9	232.7	256.6	280.4				19
17			77.1	105.1	133.0	161.0	188.9	216.9	244.8	272.8	300.7	328.7	356.6			13
18			89.1	121.4	153.7	186.1	218.4	250.7	283.0	315.4	347.7	380.0	412.4			23
19			101.8	138.8	175.7	212.7	249.7	286.6	323.6	360.6	397.6	434.5	471.5	508.5		13
20				157.1	199.0	240.8	282.7	324.6	366.5	408.4	450.2	492.1	534.0	575.9		9
21				176.4	223.4	270.5	317.5	364.6	411.7	458.7	505.8	552.8	599.9	646.9	694.0	5
22				196.7	249.2	301.7	354.1	406.6	459.1	511.6	564.1	616.6	669.1	721.6	774.1	12
23				217.9	276.1	334.3	392.5	450.7	508.9	567.1	625.3	683.5	741.7	799.9	858.0	3
24				240.2	304.3	368.5	432.7	496.8	561.0	625.1	689.3	753.4	817.6	881.7	945.9	6
25					333.8	404.2	474.6	544.9	615.3	685.7	756.1	826.5	896.8	967.2	1037.6	2
26					364.5	441.4	518.2	595.1	672.0	748.8	825.7	902.6	979.4	1056.3	1133.2	2
27					396.4	480.0	563.7	647.3	730.9	814.5	898.1	981.8	1065.4	1149.0	1232.6	1
28					429.6	520.2	610.9	701.5	792.1	882.8	973.4	1064.0	1154.7	1245.3	1335.9	0
29					464.0	561.9	659.8	757.7	855.7	953.6	1051.5	1149.4	1247.3	1345.2	1443.1	1
30						605.1	710.6	816.0	921.5	1026.9	1132.4	1237.8	1343.3	1448.7	1554.2	0
31						649.8	763.0	876.3	989.6	1102.8	1216.1	1329.3	1442.6	1555.8	1669.1	0
32						696.0	817.3	938.6	1059.9	1181.2	1302.6	1423.9	1545.2	1666.5	1787.8	0
33						743.7	873.3	1003.0	1132.6	1262.2	1391.9	1521.5	1651.2	1780.8	1910.5	0
34						792.9	931.1	1069.3	1207.6	1345.8	1484.0	1622.3	1760.5	1898.7	2036.9	0
35							990.7	1137.7	1284.8	1431.9	1579.0	1726.1	1873.1	2020.2	2167.3	0
36							1052.0	1208.2	1364.4	1520.5	1676.7	1832.9	1989.1	2145.3	2301.5	0
37							1115.0	1280.6	1446.2	1611.7	1777.3	1942.9	2108.4	2274.0	2439.6	0
38							1179.9	1355.1	1530.3	1705.5	1880.7	2055.9	2231.1	2406.3	2581.5	0
39							1246.5	1431.6	1616.7	1801.8	1986.9	2172.0	2357.1	2542.2	2727.3	0
40								1510.1	1705.4	1900.7	2095.9	2291.2	2486.5	2681.7	2877.0	0
41								1590.7	1796.4	2002.1	2207.8	2413.4	2619.1	2824.8	3030.5	0
42								1673.3	1889.6	2106.0	2322.4	2538.8	2755.1	2971.5	3187.9	0
43								1757.9	1985.2	2212.5	2439.9	2667.2	2894.5	3121.8	3349.2	0
44								1844.5	2083.0	2321.6	2560.1	2798.7	3037.2	3275.7	3514.3	0
45									2183.2	2433.2	2683.2	2933.2	3183.2	3433.2	3683.2	0
46									2285.6	2547.4	2809.1	3070.8	3332.6	3594.3	3856.1	0
47									2390.3	2664.1	2937.8	3211.6	3485.3	3759.0	4032.8	0
48									2497.3	2783.3	3069.3	3355.3	3641.3	3927.3	4213.4	0
49									2606.6	2905.2	3203.7	3502.2	3800.7	4099.3	4397.8	0
50									2718.2	3029.5	3340.8	3652.1	3963.5	4274.8	4586.1	0
BASIS TREES	0	0	27	97	131	79	44	17	4	2	1	0	0	0	0	

LINCOLN N.E.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.3	.6	.9	1.3	1.6	1.9	2.3									3
8	1.1	2.3	3.5	4.7	6.0	7.4	8.8	10.2								6
9	2.1	4.7	7.3	9.9	12.6	15.4	18.3	21.4	24.5							2
10		7.7	12.0	16.3	20.8	25.5	30.3	35.4	40.6							6
11		11.3	17.5	23.9	30.4	37.3	44.4	51.8	59.5	67.2						3
12		15.2	23.7	32.4	41.4	50.7	60.4	70.5	80.9	91.5						5
13		19.7	30.7	41.9	53.5	65.6	78.2	91.3	104.7	118.4	132.3					3
14		24.5	38.3	52.3	66.8	81.9	97.7	114.0	130.8	147.9	165.2					2
15			46.5	63.6	81.2	99.6	118.8	138.7	159.1	179.9	201.0	222.2				2
16			55.3	75.7	96.7	118.7	141.5	165.2	189.5	214.4	239.5	264.8				3
17			64.8	88.6	113.3	139.0	165.8	193.6	222.1	251.2	280.7	310.4	340.1			3
18			74.8	102.4	131.0	160.7	191.7	223.8	256.8	290.5	324.6	358.9	393.2			2
19			85.5	117.1	149.7	183.7	219.2	255.9	293.6	332.1	371.1	410.3	449.6	488.9		3
20				132.5	169.5	208.0	248.2	289.8	332.5	376.2	420.3	464.7	509.2	553.7		2
21				148.8	190.4	233.7	278.8	325.5	373.5	422.5	472.1	522.0	572.1	622.1	671.9	1
22				166.0	212.3	260.6	310.9	363.0	416.6	471.3	526.6	582.3	638.1	693.8	749.5	1
23				183.9	235.3	288.8	344.6	402.4	461.8	522.4	583.7	645.4	707.3	769.1	830.8	
24				202.7	259.3	318.3	379.8	443.5	509.0	575.8	643.4	711.5	779.7	847.8	915.8	
25					284.4	349.1	416.6	486.5	558.3	631.6	705.8	780.4	855.3	930.0	1004.6	
26					310.6	381.3	454.9	531.3	609.7	689.8	770.8	853.3	934.0	1015.7	1097.1	
27					337.8	414.7	494.8	577.9	663.2	750.3	838.4	927.1	1016.0	1104.8	1193.4	
28					366.0	449.4	536.3	626.3	718.8	813.1	908.7	1004.8	1101.1	1197.4	1293.5	
29					395.3	485.4	579.3	676.5	776.4	878.4	981.5	1085.4	1189.5	1293.5	1397.2	
30						522.7	623.8	728.5	836.1	945.9	1057.0	1168.9	1281.0	1393.0	1504.7	
31						561.3	669.8	782.3	897.9	1015.8	1135.2	1255.3	1375.7	1496.0	1616.	
32						601.3	717.5	837.9	961.8	1088.1	1215.9	1344.6	1473.6	1602.4	1731.	
33						642.4	766.7	895.4	1027.7	1162.7	1299.3	1436.8	1574.6	1711.3	1849.1	
34						684.9	817.4	954.6	1095.8	1239.6	1385.3	1531.9	1678.9	1825.7	1972.1	
35							869.7	1015.7	1165.9	1319.3	1473.9	1629.9	1786.3	1942.5	2098.4	
36							923.5	1078.6	1238.3	1400.6	1565.2	1730.9	1896.9	2062.8	2228.5	
37							978.8	1143.2	1311.3	1484.6	1659.1	1834.7	2010.3	2185.6	2361.	
38							1035.8	1209.7	1388.6	1571.3	1755.6	1941.4	2127.7	2313.8	2499.	
39							1094.7	1278.1	1467.7	1659.7	1854.7	2051.1	2248.0	2444.	2640.6	
40								1349.1	1547.5	1750.7	1956.5	2163.6	2371.2	2578.6	2785.5	
41								1422.1	1630.9	1844.3	2060.9	2279.1	2497.3	2715.	2932.3	
42								1497.8	1714.7	1939.9	2167.9	2397.1	2627.1	2857.	3086.5	
43								1569.3	1801.4	2038.1	2277.6	2518.1	2760.3	3002.8	3245.1	
44								1646.1	1890.2	2138.5	2389.8	6642.8	2896.4	3149.8	3403.5	
45									1981.3	2243.2	2506.2	2769.4	3033.1	3296.7	3560.1	
46									2074.1	2346.4	2622.3	2898.4	3174.7	3451.2	3727.5	
47									2169.7	2452.9	2740.1	3027.5	3315.1	3602.8	3890.4	
48									2266.1	2560.8	2860.3	3160.0	3459.8	3759.5	4059.4	
49									2365.2	2674.0	2986.6	3299.4	3612.4	3925.3	4238.4	
50									2466.1	2789.0	3115.6	3442.4	3769.4	4096.6	4424.1	

NET SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB
BLACKJACK PINE
COCONINO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.3	.7	1.1	1.5	1.8	2.2	2.6									27
8	1.2	2.7	4.1	5.5	7.0	8.4	9.9	11.3								34
9	2.5	5.5	8.5	11.5	14.5	17.5	20.5	23.5	26.6							8
10		9.0	14.0	19.0	24.0	28.9	33.9	38.9	43.8							34
11		13.2	20.5	27.8	35.0	42.3	49.5	56.8	64.0	71.3						17
12		17.8	27.8	37.6	47.5	57.3	67.1	76.9	86.7	96.5						26
13		23.0	35.8	48.6	61.3	73.9	86.5	99.1	111.7	124.3	137.1					11
14		28.6	44.6	60.5	76.3	92.0	107.6	123.1	138.7	154.5	170.4					17
15			54.1	73.3	92.4	111.4	130.2	148.9	167.8	186.8	206.2	225.9				13
16			64.3	87.1	109.7	132.0	154.2	176.3	198.6	221.3	244.5	268.2				10
17			75.1	101.7	128.0	153.9	179.6	205.3	231.3	257.9	285.3	313.3	341.9			5
18			86.6	117.2	147.3	176.9	206.2	235.7	265.8	296.7	328.6	361.3	394.7			6
19			98.7	133.5	167.5	201.0	234.2	267.6	302.0	337.6	374.4	412.2	450.7	489.4		5
20				150.6	188.7	226.1	263.2	301.0	340.0	380.7	422.8	466.0	509.9	554.0		4
21				168.4	210.8	252.2	293.5	335.8	379.9	426.1	473.9	522.8	572.3	622.1	671.9	3
22				187.0	233.6	279.2	324.9	372.1	421.7	473.7	527.5	582.5	638.0	693.7	749.3	7
23				206.3	257.3	307.1	357.4	409.9	465.4	523.7	583.9	645.2	706.9	768.8	830.5	1
24				226.3	281.7	335.8	391.0	449.2	511.1	576.0	642.9	710.8	779.1	847.4	915.5	4
25					306.7	365.4	425.9	490.2	558.8	630.7	704.5	779.3	854.4	929.4	1004.2	2
26					332.5	395.9	461.9	532.9	608.7	687.8	768.9	850.8	932.9	1014.9	1096.7	1
27					358.8	427.2	499.3	577.3	660.5	747.3	835.9	925.2	1014.7	1104.0	1192.9	1
28					385.7	459.3	537.9	623.4	714.5	809.2	905.5	1002.6	1099.6	1196.4	1292.8	0
29					413.3	492.4	577.9	671.3	770.6	873.4	977.9	1082.8	1187.8	1292.4	1396.5	2
30						526.3	619.3	721.0	828.9	940.1	1052.8	1166.0	1279.1	1391.8	1504.0	0
31						561.3	662.2	772.6	889.2	1009.1	1130.4	1252.1	1373.6	1494.7	1615.2	0
32						597.2	706.5	825.9	951.7	1080.5	1210.7	1341.1	1471.3	1601.0	1730.1	0
33						634.3	752.4	881.2	1016.2	1154.3	1293.6	1433.0	1572.2	1710.8	1848.7	0
34						672.4	799.8	938.2	1082.9	1230.5	1379.1	1527.8	1676.2	1824.1	1971.1	0
35						711.7	848.7	997.2	1151.7	1309.0	1467.2	1625.6	1783.5	1940.8	2097.3	0
36							899.3	1057.9	1222.6	1389.8	1558.0	1726.2	1893.9	2061.0	2227.2	0
37							951.4	1120.5	1295.5	1473.0	1651.4	1829.7	2007.5	2184.6	2360.8	0
38							1005.0	1185.0	1370.6	1558.6	1747.4	1936.1	2124.3	2311.7	2498.1	0
39							1060.3	1251.2	1447.7	1646.5	1846.1	2045.5	2244.3	2442.2	2639.2	0
40								1319.3	1526.9	1736.8	1947.3	2157.7	2367.4	2576.3	2784.0	0
41								1389.2	1608.2	1829.4	2051.2	2272.8	2493.7	2713.7	2932.6	0
42								1460.9	1691.5	1924.3	2157.7	2390.8	2623.3	2854.7	3084.9	0
43								1534.5	1777.0	2021.6	2266.8	2511.7	2755.9	2999.1	3241.0	0
44								1609.8	1864.4	2121.2	2378.5	2635.6	2891.8	3146.9	3400.7	0
45									1954.0	2223.1	2492.9	2762.3	3030.8	3298.2	3564.3	0
46									2045.6	2327.4	2609.8	2891.9	3173.0	3453.0	3731.5	0
47									2139.2	2434.0	2729.4	3024.4	3318.4	3611.2	3902.5	0
48									2234.9	2543.0	2851.6	3159.8	3467.0	3772.9	4077.2	0
49									2332.7	2654.3	2976.4	3298.1	3618.8	3938.0	4255.7	0
50									2432.5	2767.9	3103.8	3439.3	3773.7	4106.6	4437.9	0
BASIS TREES	0	11	46	78	59	37	19	7	1	2	0	0	0	0	0	

NET SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB
BLACKJACK PINE

BLACKJACK PINE
TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	RATIO TREES
7	.3	.7	1.1	1.4	1.8	2.1	2.4									29
8	1.2	2.7	4.1	5.5	6.8	8.1	9.3	10.6								38
9	2.5	5.5	8.5	11.4	14.2	16.8	19.4	22.1	24.8							31
10		9.1	14.0	18.8	23.4	27.8	32.1	36.5	41.2							42
11		13.2	20.4	27.5	34.3	40.8	47.1	53.5	60.3	67.6						32
12		17.9	27.8	37.3	46.6	55.4	64.1	72.8	82.1	92.0						24
13		23.1	35.9	48.3	60.3	71.7	82.9	94.3	106.2	119.0	132.4					22
14		28.8	44.7	60.3	75.2	89.6	103.5	117.7	132.7	148.7	165.5					14
15			54.3	73.2	91.9	108.9	125.9	143.2	161.4	180.9	201.3	222.2				15
16			64.6	87.2	108.9	129.7	150.0	170.6	192.2	215.5	239.8	264.8				6
17			75.7	102.1	127.6	152.0	175.7	199.9	225.4	252.6	281.1	310.3	339.9			10
18			87.4	118.0	147.5	175.7	203.2	231.1	260.6	292.1	325.0	358.8	393.1			10
19			99.9	134.9	168.6	200.8	232.3	264.2	298.0	333.9	371.4	410.3	449.4	488.7		7
20				152.7	190.9	227.4	263.0	299.3	337.4	378.2	420.8	464.7	509.0	553.5		4
21				171.5	214.3	255.4	295.4	336.1	379.0	424.8	472.7	522.1	571.8	621.8	671.7	3
22				191.2	239.6	284.8	329.5	374.8	423.7	473.8	527.3	582.3	637.8	693.5	749.2	1
23				211.9	266.9	315.7	365.2	415.4	468.6	523.8	584.4	645.4	706.9	768.8	830.7	1
24				233.5	295.1	348.0	402.5	457.9	516.3	578.9	644.3	711.4	779.3	847.5	915.5	1
25					324.1	381.7	441.5	502.3	566.6	635.7	706.7	780.4	854.9	929.6	1004.1	
26					349.7	416.8	481.1	548.5	618.7	693.5	771.8	852.3	933.6	1015.1	1096.8	
27					381.3	453.3	524.4	596.6	673.3	754.4	839.5	927.1	1015.5	1104.1	1192.6	
28					412.1	491.0	568.1	646.4	729.4	817.1	909.8	1004.7	1100.6	1196.9	1293.1	
29					445.1	530.6	613.8	698.4	787.8	883.1	983.8	1085.8	1188.9	1292.9	1396.8	
30						571.4	661.1	752.1	848.4	951.1	1058.4	1168.7	1280.4	1392.4	1504.7	
31						613.6	709.9	807.7	911.1	1021.1	1136.6	1255.1	1375.1	1495.6	1616.5	
32						657.3	760.7	865.0	975.9	1093.9	1217.5	1344.4	1473.9	1603.4	1732.4	
33						702.0	812.5	924.5	1042.3	1168.9	1301.1	1437.5	1575.9	1714.8	1853.6	
34						748.7	866.4	985.7	1111.3	1246.1	1387.1	1531.7	1678.7	1826.9	1975.1	
35							921.6	1048.7	1183.2	1326.6	1475.9	1629.7	1785.9	1942.7	2099.4	
36							978.7	1113.6	1256.7	1408.1	1566.4	1729.6	1896.0	2062.9	2229.6	
37							1037.7	1180.4	1331.6	1492.6	1661.1	1834.1	2009.8	2185.5	2361.0	
38							1098.7	1249.3	1409.4	1579.2	1757.1	1940.8	2126.8	2313.8	2500.6	
39							1159.6	1319.6	1488.6	1668.6	1857.1	2051.1	2248.0	2445.8	2643.4	
40								1391.8	1570.2	1761.1	1959.2	2163.5	2371.2	2579.0	2786.7	
41								1464.1	1652.0	1853.4	2062.3	2278.0	2496.7	2715.6	2934.5	
42								1536.3	1733.9	1945.7	2166.4	2392.5	2621.5	2850.6	3079.5	
43								1608.5	1815.9	2038.0	2270.5	2506.9	2746.4	2985.8	3225.1	
44								1680.7	1897.9	2130.3	2374.6	2621.4	2871.2	3121.0	3370.6	
45								1752.9	1980.0	2222.6	2478.7	2735.8	2996.1	3256.2	3516.2	
46								1825.1	2062.0	2314.9	2582.8	2850.3	3120.9	3391.4	3661.7	
47								1897.3	2144.1	2407.2	2686.9	2964.7	3245.8	3526.6	3807.3	
48								1969.5	2226.2	2499.5	2791.0	3079.2	3370.6	3661.8	3952.8	
49								2041.7	2308.3	2591.8	2895.1	3193.6	3495.5	3797.0	4098.4	
50								2114.0	2390.4	2684.1	2999.2	3308.1	3620.3	3932.2	4243.9	
51								2186.2	2472.5	2776.4	3103.3	3422.5	3745.2	4067.4	4389.5	
52								2258.4	2554.6	2868.7	3207.4	3536.9	3870.0	4202.6	4535.0	
53								2330.6	2636.7	2961.0	3311.5	3651.3	3994.9	4337.8	4680.6	
54								2402.8	2718.8	3053.3	3415.6	3765.7	4119.8	4473.0	4826.1	
55								2475.0	2800.9	3145.6	3519.7	3880.1	4244.7	4608.2	4971.7	
56								2547.2	2883.0	3237.9	3623.8	3994.5	4369.6	4743.4	5117.2	
57								2619.4	2965.2	3330.2	3727.9	4108.9	4494.5	4878.6	5262.8	
58								2691.6	3047.3	3422.5	3832.0	4223.3	4619.4	5013.8	5408.3	
59								2763.8	3129.5	3514.8	3936.1	4337.7	4744.3	5149.0	5553.9	
60								2836.0	3211.6	3607.1	4040.2	4452.1	4869.2	5284.2	5699.4	

TOTAL STEM GROSS CUBIC FOOT VOLUME-UNBORKED TREES
BLACKJACK PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	RATIO TO
1	.1	.1	.1	.1	.2	.2	.2									
2	.1	.2	.3	.4	.5	.5	.6	.7								
3	.2	.4	.6	.8	1.0	1.2	1.3	1.5	1.7							
4	.4	.7	1.0	1.4	1.7	2.0	2.3	2.7	3.0							
5	.6	1.1	1.6	2.1	2.6	3.1	3.6	4.1	4.7	5.2						
6	.8	1.5	2.3	3.0	3.7	4.5	5.2	6.0	6.7	7.4						
7	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1					15
8	1.4	2.7	4.0	5.3	6.6	7.9	9.2	10.5	11.9	13.2	14.5					20
9	1.7	3.4	5.0	6.7	8.3	10.0	11.7	13.3	15.0	16.7	18.3	20.2				14
10		4.1	6.2	8.2	10.3	12.3	14.4	16.4	18.5	20.5	22.6	24.6				15
11		5.0	7.5	10.0	12.4	14.9	17.4	19.9	22.4	24.8	27.3	29.8	32.3			23
12		6.0	8.9	11.9	14.8	17.8	20.7	23.7	26.6	29.6	32.5	35.5	38.4			17
13		7.0	10.4	13.9	17.4	20.8	24.3	27.8	31.2	34.7	38.2	41.6	45.1	48.5		15
14		8.1	12.1	16.1	20.1	24.2	28.2	32.2	36.2	40.2	44.2	48.3	52.3	56.3		18
15			13.9	18.5	23.1	27.7	32.3	36.9	41.6	46.2	50.8	55.4	60.0	64.6	69.2	13
16			15.8	21.0	26.3	31.5	36.8	42.0	47.3	52.5	57.8	63.0	68.3	73.5	78.8	10
17			17.8	23.7	29.7	35.6	41.5	47.4	53.4	59.3	65.2	71.1	77.1	83.0	88.9	11
18			20.0	26.6	33.3	39.9	46.5	53.2	59.8	66.5	73.1	79.7	86.4	93.0	99.7	13
19			22.2	29.6	37.0	44.4	51.8	59.2	66.6	74.0	81.4	88.8	96.2	103.6	111.0	3
20				32.8	41.0	49.2	57.4	65.6	73.8	82.0	90.2	98.4	106.6	114.8	123.0	5
21				36.2	45.2	54.3	63.3	72.4	81.4	90.4	99.5	108.5	117.6	126.6	135.6	4
22				39.7	49.7	59.6	69.5	79.4	89.3	99.3	109.2	119.1	129.0	138.9	148.9	1
23				43.4	54.3	65.1	75.9	86.8	97.6	108.5	119.3	130.2	141.0	151.8	162.7	3
24				47.3	59.1	70.9	82.7	94.5	106.3	118.1	129.9	141.7	153.5	165.3	177.1	0
25					64.1	76.9	89.7	102.5	115.3	128.2	141.0	153.8	166.6	179.4	192.2	1
26					69.3	83.2	97.0	110.9	124.8	138.6	152.5	166.3	180.2	194.0	207.9	1
27					74.8	89.7	104.6	119.6	134.5	149.5	164.4	179.4	194.3	209.2	224.2	0
28					80.4	96.5	112.5	128.6	144.7	160.7	176.8	192.9	209.0	225.0	241.1	0
29					86.2	103.5	120.7	138.0	155.2	172.4	189.7	206.9	224.1	241.4	258.6	0
30						110.7	129.2	147.6	166.1	184.5	203.0	221.4	239.9	258.3	276.8	0
31						118.2	137.9	157.6	177.3	197.0	216.7	236.4	256.1	275.8	295.5	0
32						126.0	147.0	168.0	188.9	209.9	230.9	251.9	272.9	293.9	314.9	0
33						134.0	156.3	178.6	200.9	223.3	245.6	267.9	290.2	312.5	334.9	0
34						142.2	165.9	189.6	213.3	237.0	260.7	284.4	308.1	331.8	355.5	0
35							175.8	200.9	226.0	251.1	276.2	301.4	326.5	351.6	376.7	0
36							186.0	212.6	239.1	265.7	292.3	318.8	345.4	371.9	398.5	0
37							196.5	224.5	252.6	280.7	308.7	336.8	364.8	392.9	421.0	0
38							207.2	236.8	266.4	296.0	325.6	355.2	384.8	414.4	444.0	0
39							218.3	249.5	280.6	311.8	343.0	374.2	405.3	436.5	467.7	0
40								262.4	295.2	328.0	360.8	393.6	426.4	459.2	492.0	0
41								275.7	310.1	344.6	379.1	413.5	448.0	482.4	516.9	0
42								289.3	325.5	361.6	397.8	433.9	470.1	506.2	542.4	0
43								303.2	341.1	379.0	416.9	454.8	492.7	530.6	568.5	0
44								317.5	357.2	396.9	436.5	476.2	515.9	555.6	595.3	0
45									373.6	415.1	456.6	498.1	539.6	581.1	622.6	0
46									390.4	433.8	477.1	520.5	563.9	607.2	650.6	0
47									407.5	452.8	498.1	543.4	588.7	633.9	679.2	0
48									425.1	472.3	519.5	566.7	614.0	661.2	708.4	0
49									443.0	492.2	541.4	590.6	639.8	689.0	738.2	0
50									461.2	512.5	563.7	615.0	666.2	717.4	768.7	0

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.1															0
2	.1	.2														0
3	.2	.4	.6													0
4	.4	.7	1.0	1.3												0
5	.6	1.1	1.6	2.0	2.5											5
6	.8	1.5	2.2	2.9	3.6	4.3										5
7	1.0	2.0	3.0	4.0	5.0	5.9	6.9									18
8	1.4	2.6	3.9	5.2	6.5	7.8	9.0	10.3								25
9	1.7	3.3	5.0	6.6	8.2	9.8	11.4	13.0	14.6							25
10		4.1	6.1	8.1	10.1	12.1	14.1	16.1	18.0							19
11		5.0	7.4	9.9	12.3	14.7	17.1	19.5	21.8	24.2						28
12		5.9	8.8	11.7	14.6	17.5	20.3	23.2	26.0	28.8						23
13		6.9	10.3	13.7	17.1	20.5	23.9	27.2	30.5	33.8	37.0					26
14		8.0	12.0	15.9	19.9	23.8	27.7	31.5	35.3	39.1	42.9					26
15			13.8	18.3	22.8	27.3	31.7	36.2	40.5	44.9	49.2	53.5				19
16			15.6	20.8	25.9	31.0	36.1	41.1	46.1	51.0	55.9	60.8				13
17			17.6	23.5	29.3	35.0	40.7	46.4	52.0	57.6	63.1	68.5	74.0			14
18			19.8	26.3	32.8	39.2	45.6	51.9	58.2	64.5	70.6	76.8	82.9			15
19			22.0	29.3	36.5	43.7	50.8	57.8	64.8	71.8	78.6	85.5	92.3	99.1		7
20				32.4	40.4	48.3	56.2	64.0	71.7	79.4	87.1	94.7	102.3	109.8		5
21				35.7	44.5	53.2	61.9	70.5	79.0	87.5	96.0	104.4	112.7	121.1	129.4	4
22				39.2	48.8	58.4	67.9	77.3	86.7	96.0	105.3	114.5	123.8	133.0	142.2	1
23				42.8	53.3	63.7	74.1	84.4	94.6	104.9	115.1	125.2	135.4	145.5	155.6	3
24				46.6	58.0	69.3	80.6	91.8	103.0	114.2	125.3	136.4	147.5	158.6	169.6	2
25					62.9	75.2	87.4	99.6	111.7	123.8	136.0	148.1	160.1	172.2	184.2	1
26					67.9	81.2	94.4	107.6	120.8	134.0	147.1	160.2	173.3	186.4	199.5	1
27					73.2	87.5	101.8	116.0	130.3	144.5	158.7	172.9	187.1	201.2	215.4	0
28					78.6	94.0	109.4	124.8	140.1	155.4	170.7	186.0	201.3	216.6	231.8	0
29					84.3	100.8	117.3	133.8	150.3	166.8	183.2	199.7	216.1	232.5	248.9	0
30						107.8	125.5	143.2	160.9	178.5	196.2	213.8	231.4	249.0	266.6	0
31						115.1	134.0	152.9	171.8	190.7	209.6	228.4	247.2	266.1	284.8	0
32						122.6	142.8	162.9	183.1	203.2	223.4	243.5	263.6	283.7	303.7	
33						130.3	151.8	173.3	194.8	216.2	237.7	259.1	280.5	301.8	323.2	
34						138.3	161.1	184.0	206.8	229.6	252.4	275.1	297.9	320.6	343.4	
35							170.8	195.0	219.1	243.4	267.5	291.7	315.8	339.9	363.9	
36							180.7	206.3	231.9	257.5	283.1	308.7	334.2	359.7	385.2	
37							190.9	218.0	245.1	272.1	299.2	326.2	353.2	380.1	407.1	
38							201.3	229.9	258.5	287.1	315.7	344.2	372.7	401.1	429.6	
39							212.1	242.2	272.4	302.5	332.6	362.6	392.6	422.6	452.6	
40								254.9	286.4	318.3	349.9	381.6	413.2	444.8	476.3	
41								267.8	301.1	334.5	367.7	401.0	434.2	467.4	500.6	
42								281.1	316.1	351.0	386.0	420.9	455.8	490.6	525.5	
43								294.7	331.3	368.1	404.7	441.3	477.8	514.4	550.9	
44								308.6	347.0	385.4	423.8	462.1	500.4	538.7	577.1	
45									363.0	403.2	443.3	483.5	523.6	563.6	603.7	
46									379.4	421.4	463.4	505.3	547.1	589.0	630.9	
47									396.1	439.9	483.8	527.6	571.4	615.1	658.8	
48									413.2	458.9	504.6	550.3	596.0	641.7	687.4	
49									430.6	478.4	526.1	573.8	621.6	669.3	716.9	
50									448.4	498.1	547.7	597.3	646.9	696.6	746.2	

4451																
7414	0	28	47	59	60	48	34	19	4							

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNMARKED TREES
BLACKJACK PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.2	.3	.5	.6	.8											6
6	.5	.9	1.4	1.8	2.3	2.7										9
7	.7	1.5	2.3	3.1	3.8	4.6	5.4									14
8	1.0	2.1	3.3	4.4	5.5	6.6	7.8	8.9								20
9	1.3	2.8	4.3	5.8	7.3	8.8	10.3	11.8	13.3							17
10		3.5	5.4	7.4	9.3	11.2	13.1	15.0	17.0							1
11		4.3	6.7	9.1	11.4	13.8	16.2	18.5	20.9	23.2						1
12		5.2	8.0	10.9	13.7	16.6	19.4	22.3	25.1	28.0						17
13		6.1	9.5	12.9	16.2	19.6	23.0	26.4	29.7	33.1	36.5					1
14		7.1	11.0	15.0	18.9	22.8	26.8	30.7	34.7	38.6	42.5					14
15			12.7	17.2	21.8	26.3	30.9	35.4	39.9	44.5	49.0	53.5				13
16			14.5	19.7	24.8	30.0	35.2	40.4	45.6	50.7	55.9	61.1				10
17			16.4	22.2	28.1	34.0	39.8	45.7	51.5	57.4	63.3	69.1	75.0			11
18			18.4	24.9	31.5	38.1	44.7	51.3	57.9	64.5	71.0	77.6	84.2			13
19			20.5	27.8	35.2	42.5	49.9	57.2	64.6	71.9	79.3	86.6	94.0	101.3		8
20				30.8	39.0	47.1	55.3	63.4	71.6	79.7	87.9	96.0	104.2	112.4		5
21				34.0	43.0	52.0	61.0	70.0	79.0	88.0	97.0	106.0	115.0	124.0	133.0	4
22				37.3	47.2	57.1	67.0	76.9	86.7	96.6	106.5	116.4	126.3	136.1	146.0	1
23				40.8	51.6	62.4	73.2	84.0	94.8	105.6	116.4	127.3	138.1	148.9	159.7	3
24				44.4	56.2	68.0	79.8	91.5	103.3	115.1	126.8	138.6	150.4	162.1	173.9	0
25					61.0	73.8	86.6	99.3	112.1	124.9	137.7	150.4	163.2	176.0	188.8	1
26					66.0	79.8	93.6	107.5	121.3	135.1	148.9	162.8	176.6	190.4	204.2	1
27					71.2	86.1	101.0	115.9	130.8	145.7	160.6	175.6	190.5	205.4	220.3	0
28					76.5	92.6	108.6	124.7	140.7	156.8	172.8	188.8	204.9	220.9	237.0	0
29					82.1	99.3	116.5	133.7	151.0	168.2	185.4	202.6	219.8	237.0	254.2	0
30						106.3	124.7	143.1	161.6	180.0	198.4	216.8	235.3	253.7	272.1	0
31						113.5	133.2	152.9	172.5	192.2	211.9	231.6	251.2	270.9	290.6	0
32						121.0	141.9	162.9	183.9	204.8	225.8	246.8	267.7	288.7	309.6	0
33						128.6	150.9	173.2	195.5	217.8	240.1	262.4	284.7	307.0	329.3	0
34						136.6	160.2	183.9	207.6	231.2	254.9	278.6	302.3	325.9	349.6	0
35							169.8	194.9	220.0	245.1	270.2	295.2	320.3	345.4	370.5	0
36							179.6	206.2	232.7	259.3	285.8	312.4	338.9	365.5	392.0	0
37							189.8	217.8	245.8	273.9	301.9	330.0	358.0	386.1	414.1	0
38							200.2	229.7	259.3	288.9	318.5	348.1	377.6	407.2	436.8	0
39							210.8	242.0	273.2	304.3	335.5	366.6	397.8	428.9	460.1	0
40								254.6	287.3	320.1	352.9	385.7	418.5	451.2	484.0	0
41								267.5	301.9	336.3	370.8	405.2	439.7	474.1	508.5	0
42								280.7	316.8	352.9	389.1	425.2	461.4	497.5	533.7	0
43								294.2	332.1	370.0	407.8	445.7	483.6	521.5	559.4	0
44								308.0	347.7	387.4	427.0	466.7	506.4	546.0	585.7	0
45									363.7	405.2	446.7	488.2	529.7	571.1	612.6	0
46									380.0	423.4	466.7	510.1	553.5	596.8	640.2	0
47									396.7	442.0	487.3	532.5	577.8	623.1	668.3	0
48									413.8	461.0	508.2	555.4	602.6	649.9	697.1	0
49									431.2	480.4	529.6	578.8	628.0	677.2	726.4	0
50									449.0	500.2	551.5	602.7	653.9	705.2	756.4	0
BASIS TREES	0	9	38	49	45	37	22	13	4	2	0	0	0	0	0	

SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
5	.2	.3	.5	.6	.7											5
6	.5	.9	1.3	1.8	2.2	3.7										1
7	.7	1.5	2.2	3.0	3.8	4.5	5.2									1
8	1.0	2.1	3.2	4.3	5.4	6.5	7.6	8.6								2
9	1.3	2.8	4.2	5.7	7.2	8.7	10.1	11.5	13.0							2
10		3.5	5.4	7.3	9.1	11.0	12.9	14.7	16.5							1
11		4.3	6.6	9.0	11.3	13.6	15.9	18.1	20.4	22.6						2
12		5.1	8.0	10.8	13.6	16.3	19.1	21.8	24.5	27.3						2
13		6.1	9.4	12.7	16.0	19.3	22.6	25.8	29.0	32.2	35.4					2
14		7.1	10.9	14.8	18.7	22.5	26.3	30.1	33.9	37.6	41.3					2
15			12.6	17.1	21.5	25.9	30.3	34.7	39.0	43.3	47.5	51.7				1
16			14.4	19.5	24.5	29.5	34.6	39.6	44.5	49.4	54.2	59.0				1
17			16.2	22.0	27.7	33.4	39.1	44.7	50.3	55.8	61.3	66.7	72.1			1
18			18.2	24.7	31.1	37.5	43.9	50.2	56.5	62.7	68.8	74.9	81.			1
19			20.3	27.5	34.7	41.8	48.9	56.0	62.9	69.9	76.7	83.5	90.3	97.1		1
20				30.5	38.5	46.4	54.2	62.1	69.7	77.4	85.1	92.6	100.	107.7		
21				33.6	42.4	51.1	59.8	68.4	76.9	85.4	93.8	102.2	110.6	118.9	127.1	
22				36.9	46.5	56.1	65.6	75.2	84.4	93.7	103.0	112.3	121.5	130.	139.9	1
23				40.3	50.8	61.3	71.7	82.0	92.2	102.5	112.7	122.9	133.	144.1	155.1	
24				43.9	55.3	66.7	78.1	89.3	100.5	111.6	122.8	133.9	145.0	156.1	167.1	
25					60.0	72.3	84.6	96.8	109.0	121.1	133.3	145.4	157.5	169.6	181.6	1
26					64.9	78.1	91.5	104.8	118.0	131.1	144.1	157.1	170.0	183.	196.0	1
27					69.9	84.2	98.4	112.6	126.8	141.0	155.2	169.3	183.3	197.	210.8	
28					75.1	90.5	106.1	121.5	136.9	152.2	167.4	182.5	198.	213.4	228.8	
29					80.6	97.2	113.8	130.3	146.8	163.2	179.5	196.4	213.	229.	245.7	
30						104.2	121.7	139.5	157.2	174.9	192.6	210.0	227.5	245.0	262.4	
31						111.4	130.0	149.1	167.9	186.9	205.8	224.6	243.4	262.1	281.	
32						118.7	138.5	158.8	179.0	199.	219.0	239.0	259.0	278.9	298.8	
33						126.2	147.3	168.8	190.4	212.	233.5	255.	276.4	297.7	319.0	
34						133.9	156.4	179.3	202.2	225.1	248.0	270.8	293.6	316.3	339.0	
35							165.7	190.1	214.4	238.6	262.9	287.1	311.3	335.4	359.4	
36							175.4	201.1	226.9	252.6	278.4	304.1	329.7	355.3	380.8	
37							185.4	212.5	239.7	266.9	294.1	321.2	348.3	375.4	402.4	
38							195.6	224.1	252.9	281.6	310.3	338.9	367.5	396.0	424.5	
39							206.	236.0	266.0	296.0	326.0	355.9	385.8	415.6	445.4	
40							216.5	248.0	279.4	311.0	342.5	374.0	405.4	436.8	468.2	
41							227.1	260.1	293.1	326.1	359.1	392.1	425.1	458.1	491.1	
42							238.1	272.4	306.7	341.0	375.3	409.6	443.9	478.2	512.4	
43							249.3	284.9	320.5	356.1	391.7	427.3	462.9	498.5	534.1	
44							260.7	297.6	334.5	371.4	408.3	445.2	482.1	519.0	555.9	
45							272.3	310.5	348.7	386.9	425.1	463.3	501.5	539.7	577.9	
46							284.1	323.6	363.1	402.6	442.1	481.6	521.1	560.6	600.1	
47							296.1	337.0	377.8	418.6	459.4	500.2	541.0	581.8	622.6	
48							308.4	350.8	393.2	435.6	478.0	520.4	562.8	605.2	647.6	
49							320.8	364.8	408.8	452.8	496.8	540.8	584.8	628.8	672.8	
50							333.5	379.1	424.7	470.3	515.9	561.5	607.1	652.7	698.3	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES-UNFORKED TREES
BLACKJACK PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.2	.4	.7	.9	1.2	1.4	1.7									13
8	.6	1.3	1.9	2.6	3.3	4.0	4.7	5.4								20
9	.9	2.1	3.2	4.3	5.5	6.6	7.8	8.9	10.0							18
10		2.9	4.5	6.1	7.7	9.3	10.9	12.5	14.1							15
11		3.8	5.9	8.0	10.1	12.2	14.3	16.4	18.4	20.5						22
12		4.7	7.3	9.9	12.5	15.2	17.8	20.4	23.0	25.6						17
13		5.7	8.8	12.0	15.2	18.3	21.5	24.7	27.8	31.0	34.2					13
14		6.7	10.5	14.2	18.0	21.7	25.5	29.2	33.0	36.7	40.5					16
15			12.2	16.6	20.9	25.3	29.7	34.0	38.4	42.8	47.1	51.5				13
16			14.0	19.0	24.1	29.1	34.1	39.1	44.2	49.2	54.2	59.3				10
17			15.9	21.7	27.4	33.1	38.8	44.6	50.3	56.0	61.7	67.4	73.2			11
18			18.0	24.4	30.9	37.3	43.8	50.3	56.7	63.2	69.6	76.1	82.5			13
19			20.1	27.3	34.6	41.8	49.0	56.3	63.5	70.7	77.9	85.2	92.4	99.6		3
20				30.4	38.4	46.5	54.5	62.6	70.6	78.6	86.7	94.7	102.8	110.8		5
21				33.6	42.5	51.4	60.3	69.2	78.1	87.0	95.8	104.7	113.6	122.5	131.4	4
22				36.9	46.7	56.5	66.3	76.1	85.9	95.7	105.4	115.2	125.0	134.8	144.6	1
23				40.5	51.2	61.9	72.6	83.3	94.0	104.7	115.5	126.2	136.9	147.6	158.3	3
24				44.1	55.8	67.5	79.2	90.9	102.5	114.2	125.9	137.6	149.3	161.0	172.7	0
25					60.6	73.3	86.0	98.7	111.4	124.1	136.8	149.5	162.2	174.9	187.6	1
26					65.6	79.4	93.1	106.9	120.6	134.4	148.1	161.9	175.6	189.4	203.1	1
27					70.8	85.7	100.5	115.3	130.2	145.0	159.9	174.7	189.6	204.4	219.2	0
28					76.2	92.2	108.2	124.1	140.1	156.1	172.1	188.0	204.0	220.0	236.0	0
29					81.8	98.9	116.1	133.2	150.4	167.5	184.7	201.8	219.0	236.1	253.3	0
30						105.9	124.3	142.7	161.0	179.4	197.7	216.1	234.5	252.8	271.2	0
31						113.2	132.8	152.4	172.0	191.6	211.2	230.9	250.5	270.1	289.7	0
32						120.6	141.5	162.5	183.4	204.3	225.2	246.1	267.0	287.9	308.8	0
33						128.3	150.6	172.8	195.1	217.3	239.6	261.8	284.1	306.3	328.5	0
34						136.3	159.9	183.5	207.1	230.8	254.4	278.0	301.6	325.2	348.9	0
35							169.5	194.5	219.5	244.6	269.6	294.7	319.7	344.7	369.8	0
36							179.3	205.8	232.3	258.8	285.3	311.8	338.3	364.8	391.3	0
37							189.5	217.5	245.5	273.4	301.4	329.4	357.4	385.4	413.4	0
38							199.9	229.4	258.9	288.5	318.0	347.6	377.1	406.6	436.2	0
39							210.6	241.7	272.8	303.9	335.0	366.1	397.3	428.4	459.5	0
40								254.3	287.0	319.7	352.5	385.2	418.0	450.7	483.4	0
41								267.2	301.6	336.0	370.4	404.8	439.2	473.6	508.0	0
42								280.4	316.5	352.6	388.7	424.8	460.9	497.0	533.1	0
43								293.9	331.8	369.6	407.5	445.3	483.2	521.0	558.9	0
44								307.8	347.4	387.0	426.7	466.3	505.9	545.6	585.2	0
45									363.4	404.9	446.3	487.8	529.2	570.7	612.1	0
46									379.7	423.1	466.4	509.7	553.1	596.4	639.7	0
47									396.5	441.7	486.9	532.2	577.4	622.6	667.9	0
48									413.5	460.7	507.9	555.1	602.3	649.4	696.6	0
49									431.0	480.1	529.3	578.5	627.6	676.8	726.0	0
50									448.7	500.0	551.2	602.4	653.6	704.8	756.0	0
BASIS TREES	0	5	31	49	45	37	22	13	4	2	0	0	0	0	0	

NET CUBIC FOOT VOLUME TO TOP DIB OF 5 INCHES
BLACKJACK PINE

BLACKJACK PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.2	.4	.7	.9	1.2	1.4	1.6									1
8	.6	1.2	1.9	2.6	3.3	4.0	4.6	5.3								2
9	.9	2.0	3.2	4.3	5.4	6.5	7.7	8.8	9.9							2
10		2.9	4.5	6.1	7.6	9.2	10.8	12.4	13.9							1
11		3.7	5.8	7.9	10.0	12.0	14.1	16.1	18.2	20.2						2
12		4.7	7.2	9.8	12.4	15.0	17.5	20.1	22.6	25.2						2
13		5.6	8.8	11.9	15.0	18.1	21.2	24.3	27.4	30.4	33.5					3
14		6.7	10.4	14.1	17.8	21.4	25.1	28.7	32.4	36.0	39.6					2
15			12.1	16.4	20.7	24.9	29.2	33.4	37.7	41.9	46.1	50.2				1
16			13.9	18.8	23.7	28.7	33.5	38.4	43.3	48.1	52.9	57.7				1
17			15.8	21.4	27.0	32.6	38.1	43.7	49.2	54.6	60.1	65.5	71.0			1
18			17.8	24.1	30.4	36.7	43.0	49.2	55.4	61.5	67.7	73.8	79.9			1
19			19.9	27.0	34.0	41.0	48.0	55.0	61.9	68.8	75.6	82.5	89.3	96.1		
20				29.9	37.8	45.6	53.3	61.0	68.7	76.3	84.0	91.6	99.2	106.8		
21				33.1	41.7	50.3	58.9	67.4	75.8	84.3	92.7	101.2	109.6	118.0	126.4	
22				36.3	45.8	55.3	64.6	74.0	83.3	92.6	101.9	111.2	120.5	129.7	139.0	
23				39.8	50.1	60.4	70.7	80.9	91.1	101.3	111.5	121.6	131.8	142.0	152.2	
24				43.3	54.6	65.8	77.0	88.1	99.2	110.3	121.5	132.6	143.7	154.9	166.0	
25					59.2	71.4	83.5	95.6	107.7	119.8	131.9	144.0	156.1	168.2	180.4	
26					64.0	77.2	90.3	103.4	116.5	129.6	142.8	155.9	169.0	182.2	195.3	
27					69.0	83.2	97.4	111.5	125.7	139.9	154.0	168.2	182.4	196.7	210.9	
28					74.2	89.4	104.7	119.9	135.2	150.5	165.8	181.1	196.4	211.7	227.0	
29					79.5	95.9	112.3	128.7	145.1	161.5	177.9	194.3	210.8	227.2	243.7	
30						102.6	120.1	137.7	155.3	172.9	190.5	208.1	225.7	243.4	261.0	
31						109.5	128.3	147.0	165.8	184.7	203.5	222.4	241.1	260.0	278.8	
32						116.6	136.7	156.7	176.8	196.8	216.9	237.0	257.1	277.3	297.3	
33						124.0	145.3	166.7	188.0	209.4	230.8	252.2	273.6	295.0	316.3	
34						131.6	154.3	176.9	199.6	222.4	245.1	267.8	290.5	313.2	335.9	
35							163.5	187.5	211.6	235.7	259.8	283.9	307.9	332.0	356.1	
36							173.0	198.4	223.9	249.4	274.9	300.4	325.9	351.4	376.9	
37							180.7	209.7	236.6	263.5	290.5	317.4	344.4	371.3	398.3	
38							192.8	221.2	249.6	278.0	306.5	334.9	363.3	391.7	420.1	
39							203.1	233.0	263.0	293.0	322.9	352.8	382.8	412.8	442.6	
40								245.1	276.7	308.3	339.7	371.2	402.7	434.1	465.7	
41								257.6	290.7	323.9	357.0	390.1	423.2	456.3	489.4	
42								270.3	305.1	339.9	374.7	409.4	444.2	478.9	513.7	
43								283.4	319.9	356.3	392.8	429.2	465.7	502.1	538.5	
44								296.8	335.0	373.1	411.3	449.5	487.6	525.8	564.0	
45									350.4	390.1	429.7	469.4	510.1	550.7	589.9	
46									366.0	407.9	449.6	491.4	533.1	574.8	616.5	
47									381.9	425.9	469.5	513.0	556.6	600.1	643.7	
48									398.8	444.3	489.7	535.1	580.6	626.0	671.5	
49									415.6	463.1	510.6	558.1	605.5	652.9	700.3	
50									432.7	482.1	531.6	580.8	630.2	679.4	728.8	
BASIS TREES	2	15	47	66	62	44	24	15	14	11	11	7	5	3	3	

GROSS INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB-UNFORKED TREES
BLACKJACK PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.3	.6	.9	1.3	1.6	1.9	2.3									13
8	1.5	3.4	5.2	7.1	8.9	10.8	12.6	14.5								20
9	3.3	7.5	11.6	15.7	19.8	23.9	28.0	32.1	36.3							18
10		12.4	19.3	26.2	33.0	39.9	46.8	53.6	60.5							15
11		18.1	28.1	38.1	48.1	58.1	68.2	78.2	88.2	98.2						22
12		24.3	37.8	51.3	64.8	78.4	91.9	105.4	118.9	132.4						17
13		31.1	48.4	65.8	83.1	100.4	117.7	135.1	152.4	169.7	187.1					14
14		38.5	59.9	81.4	102.8	124.3	145.7	167.2	188.6	210.1	231.5					19
15			72.2	98.1	124.0	149.9	175.8	201.6	227.5	253.4	279.3	305.2				13
16			85.3	116.0	146.6	177.2	207.8	238.5	269.1	299.7	330.3	361.0				10
17			99.3	135.0	170.6	206.3	242.0	277.6	313.3	349.0	384.6	420.3	456.0			11
18			114.1	155.1	196.1	237.1	278.2	319.2	360.2	401.2	442.2	483.2	524.2			13
19			129.7	176.4	223.1	269.7	316.4	363.0	409.7	456.4	503.0	549.7	596.3	643.0		3
20				198.8	251.4	304.0	356.7	409.3	461.9	514.5	567.1	619.7	672.3	724.9		6
21				222.4	281.2	340.1	399.0	457.9	516.7	575.6	634.5	693.3	752.2	811.1	870.0	4
22				247.1	312.5	378.0	443.4	508.8	574.3	639.7	705.1	770.6	836.0	901.4	966.9	1
23				272.9	345.2	417.5	489.9	562.2	634.5	706.8	779.1	851.4	923.7	996.0	1068.3	3
24				299.9	379.4	458.9	538.4	617.9	697.3	776.8	856.3	935.8	1015.3	1094.7	1174.2	0
25					415.1	502.0	589.0	676.0	762.9	849.9	936.8	1023.8	1110.8	1197.7	1284.7	1
26					452.2	546.9	641.7	736.4	831.2	925.9	1020.7	1115.4	1210.2	1304.9	1399.7	1
27					490.7	593.6	696.4	799.3	902.1	1005.0	1107.8	1210.7	1313.5	1416.4	1519.2	0
28					530.8	642.0	753.3	864.5	975.8	1087.0	1198.3	1309.5	1420.8	1532.1	1643.3	0
29					572.3	692.2	812.2	932.2	1052.1	1172.1	1292.1	1412.0	1532.0	1652.0	1771.9	0
30						744.2	873.2	1002.2	1131.2	1260.2	1389.2	1518.2	1647.1	1776.1	1905.1	0
31						798.0	936.3	1074.6	1212.9	1351.3	1489.6	1627.9	1766.2	1904.5	2042.9	0
32						853.5	1001.5	1149.5	1297.4	1445.4	1593.3	1741.3	1889.2	2037.2	2185.2	0
33						910.9	1068.8	1226.7	1384.6	1542.5	1700.4	1858.3	2016.2	2174.1	2332.0	0
34						970.0	1138.1	1306.3	1474.5	1642.6	1810.8	1979.0	2147.1	2315.3	2483.5	0
35							1209.6	1388.3	1567.0	1745.8	1924.5	2103.3	2282.0	2460.7	2639.5	0
36							1283.1	1472.7	1662.3	1852.0	2041.6	2231.2	2420.8	2610.4	2800.0	0
37							1358.8	1559.6	1760.4	1961.2	2162.0	2362.8	2563.6	2764.3	2965.1	0
38							1436.5	1648.8	1861.1	2073.4	2285.7	2498.0	2710.3	2922.6	3134.8	0
39							1516.3	1740.4	1964.5	2188.6	2412.7	2636.8	2860.9	3085.0	3309.1	0
40								1834.5	2070.7	2306.9	2543.1	2779.3	3015.5	3251.8	3488.0	0
41								1930.9	2179.5	2428.2	2676.8	2925.5	3174.1	3422.8	3671.4	0
42								2029.7	2291.1	2552.5	2813.9	3075.3	3336.6	3598.0	3859.4	0
43								2131.0	2405.4	2679.8	2954.3	3228.7	3503.1	3777.5	4052.0	0
44								2234.7	2522.4	2810.2	3098.0	3385.8	3673.6	3961.3	4249.1	0
45									2642.2	2943.6	3245.1	3546.5	3848.0	4149.4	4450.9	0
46									2764.6	3080.0	3395.5	3710.9	4026.3	4341.7	4657.2	0
47									2889.8	3219.5	3549.2	3878.9	4208.6	4538.3	4868.1	0
48									3017.7	3362.0	3706.3	4050.6	4394.9	4739.2	5083.5	0
49									3148.3	3507.5	3866.7	4225.9	4585.1	4944.4	5303.6	0
50									3281.6	3656.0	4030.5	4404.9	4779.3	5153.8	5528.2	0
BASIS TREES	0	4	32	49	44	37	22	14	4	2	0	0	0	0	0	

NET INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB

BLACKJACK PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS															BASIC TREES
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
7	.2	.6	.9	1.2	1.5	1.8	2.2									14
8	1.5	3.2	5.0	6.7	8.4	10.1	11.9	13.7								29
9	3.2	7.2	11.0	14.8	18.5	22.2	26.0	30.0	34.1							29
10		11.9	18.3	24.5	30.6	36.7	42.9	49.4	56.1							19
11		17.3	26.6	35.5	44.3	53.9	61.8	71.1	80.7	90.8						17
12		23.3	35.7	47.7	59.2	70.7	82.4	94.6	107.5	120.8						23
13		29.8	45.6	60.8	75.5	89.9	104.6	119.9	136.1	152.0	170.4					22
14		36.8	56.3	75.0	92.9	110.4	128.2	146.8	166.4	187.1	208.5					7
15			67.8	90.1	111.4	132.2	153.2	175.2	198.5	223.1	248.4	274.9				14
16			80.0	106.3	131.5	155.3	179.7	205.1	232.2	260.8	290.7	321.6				13
17			92.9	123.3	152.0	179.7	207.5	236.6	267.6	300.4	334.8	370.5	406.9			14
18			106.6	141.4	174.1	205.4	236.8	269.6	304.6	341.8	380.9	421.6	463.1			11
19			121.1	160.5	197.3	232.4	267.5	304.1	343.0	385.0	428.9	474.6	521.4	567.-		7
20				180.5	221.6	260.7	299.6	340.1	383.5	429.9	478.9	529.9	582.4	636.		4
21				201.5	247.2	290.3	333.1	377.7	426.4	478.4	530.7	587.3	645.5	709.1	769.5	4
22				223.5	273.9	321.9	368.0	416.8	469.0	525.1	584.2	646.7	711.9	776.6	841.4	2
23				246.5	301.7	353.5	404.4	457.3	514.1	575.3	640.2	708.	778.6	850.7	924.	1
24				270.5	330.8	387.0	442.2	499.5	561.1	627.	697.8	771.8	848.5	927.	1007.1	1
25					361.1	421.9	481.4	543.1	609.4	681.	757.4	837.	919.7	1006.1	1093.	1
26					392.4	458.1	522.8	588.9	659.9	736.9	818.7	904.3	993.5	1086.5	1181.7	1
27					425.1	495.6	564.1	635.0	710.3	793.1	881.2	972.7	1071.7	1171.7	1273.8	1
28					458.8	534.4	607.6	683.2	764.4	853.2	947.8	1045.9	1152.6	1259.6	1369.6	1
29					493.7	574.6	653.5	733.9	819.6	914.5	1014.1	1117.8	1231.6	1346.	1465.3	1
30						616.1	698.9	784.3	876.3	976.9	1083.1	1194.	1316.	1438.	1565.4	1
31						658.9	746.7	837.1	934.9	1041.4	1154.6	1272.4	1402.9	1533.9	1670.4	1
32						703.1	796.0	891.5	995.4	1108.6	1229.1	1354.8	1493.8	1634.	1780.5	1
33						748.5	846.7	947.4	1057.9	1174.1	1301.8	1436.8	1584.	1734.	1890.	1
34						795.1	898.8	1004.9	1122.1	1244.1	1379.1	1524.9	1681.8	1841.8	2006.4	1
35							953.4	1063.9	1188.2	1317.6	1459.4	1614.5	1781.1	1950.4	2125.4	1
36							1009.4	1124.4	1255.4	1391.8	1541.8	1705.4	1881.4	2060.4	2245.4	1
37							1067.9	1186.5	1323.8	1467.8	1626.1	1798.4	1984.8	2174.7	2369.7	1
38							1127.8	1250.1	1394.2	1545.7	1712.4	1894.2	2090.4	2290.1	2495.1	1
39							1189.2	1316.	1466.6	1625.6	1800.	1991.1	2197.	2407.4	2623.1	1
40							1252.1	1383.9	1541.8	1707.5	1889.7	2089.8	2305.8	2526.1	2752.1	1
41							1316.5	1453.1	1618.2	1790.5	1980.5	2189.6	2415.6	2646.8	2883.4	1
42							1382.1	1523.6	1695.6	1874.6	2072.4	2290.4	2526.4	2767.5	3014.7	1
43							1448.9	1595.2	1774.1	1959.8	2165.4	2392.2	2638.1	2889.2	3146.9	1
44							1517.0	1668.1	1853.7	2046.1	2259.4	2495.1	2751.0	3012.9	3281.1	1
45							1586.1	1742.1	1934.4	2133.5	2354.4	2598.1	2864.0	3136.7	3415.3	1
46								1817.1	2015.1	2221.0	2449.4	2701.1	2977.0	3260.5	3549.5	1
47								1893.1	2096.8	2308.5	2544.4	2804.1	3090.0	3383.3	3683.7	1
48								1970.1	2179.6	2396.0	2639.4	2907.1	3202.9	3506.1	3817.9	1
49								2048.1	2263.4	2483.5	2734.4	3010.1	3315.8	3629.0	3952.1	1
50								2127.1	2347.2	2571.0	2829.4	3113.1	3428.8	3752.0	4086.3	1
51									2431.0	2658.5	2924.4	3216.1	3541.8	3875.0	4220.5	1
52									2515.8	2746.0	3019.4	3319.1	3654.8	3998.0	4354.7	1
53									2601.6	2833.5	3114.4	3422.1	3767.8	4121.0	4488.9	1
54									2688.5	2921.0	3209.4	3525.1	3880.8	4244.0	4623.1	1
55									2776.3	3009.5	3304.4	3628.1	3993.8	4367.0	4757.3	1
56									2864.9	3098.9	3399.4	3731.1	4106.8	4490.0	4891.5	1
57									2954.4	3188.3	3494.4	3834.1	4219.8	4613.0	5025.7	1
58									3044.8	3278.6	3589.4	3937.1	4332.8	4736.0	5159.9	1
59									3136.1	3369.8	3684.4	4040.1	4445.8	4859.0	5294.1	1
60									3228.2	3461.9	3779.4	4143.1	4558.8	4982.0	5428.3	1
61										3554.9	3874.4	4246.1	4671.8	5105.0	5562.5	1
62										3648.8	3969.4	4349.1	4784.8	5228.0	5696.7	1
63										3743.6	4064.4	4452.1	4897.8	5351.0	5830.9	1
64										3839.3	4159.4	4555.1	5010.8	5474.0	5965.1	1
65										3935.9	4254.4	4658.1	5123.8	5597.0	6099.3	1
66										4033.4	4349.4	4761.1	5236.8	5720.0	6233.5	1
67										4131.8	4444.4	4864.1	5349.8	5843.0	6367.7	1
68										4231.1	4539.4	4967.1	5462.8	5966.0	6501.9	1
69										4331.3	4634.4	5070.1	5575.8	6089.0	6636.1	1
70										4432.4	4729.4	5173.1	5688.8	6212.0	6770.3	1

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNFORKED TREES
BLACKJACK PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.1	.3	.5	.7	.8	1.0	1.2									0
8	.9	2.1	3.2	4.4	5.5	6.7	7.8	9.0								0
9	2.3	5.1	7.8	10.6	13.4	16.2	19.0	21.8	24.6							12
10		9.0	14.0	18.9	23.9	28.9	33.8	38.8	43.8							15
11		13.7	21.3	28.9	36.5	44.1	51.7	59.3	66.9	74.5						22
12		19.1	29.7	40.3	51.0	61.6	72.2	82.8	93.4	104.1						17
13		25.1	39.1	53.1	67.1	81.1	95.1	109.1	123.1	137.1	151.1					16
14		31.8	49.5	67.2	84.9	102.7	120.4	138.1	155.8	173.6	191.3					19
15			60.7	82.5	104.3	126.1	147.9	169.6	191.4	213.2	235.0	256.8				13
16			72.9	99.0	125.2	151.4	177.5	203.7	229.8	256.0	282.1	308.3				10
17			85.9	116.7	147.6	178.5	209.3	240.2	271.0	301.9	332.7	363.6	394.4			11
18			99.8	135.6	171.5	207.4	243.2	279.1	314.9	350.8	386.7	422.5	458.4			13
19			114.5	155.7	196.9	238.1	279.2	320.4	361.6	402.8	444.0	485.1	526.3	567.5		3
20				176.9	223.7	270.5	317.4	364.2	411.0	457.8	504.6	551.4	598.2	645.1		5
21				199.3	252.0	304.8	357.6	410.3	463.1	515.8	568.6	621.4	674.1	726.9	779.6	4
22				222.8	281.8	340.9	399.9	458.9	517.9	576.9	635.9	694.9	753.9	812.9	871.9	1
23				247.5	313.1	378.7	444.2	509.8	575.4	641.0	706.5	772.1	837.7	903.3	968.8	3
24				273.4	345.8	418.3	490.7	563.2	635.6	708.0	780.5	852.9	925.4	997.8	1070.3	0
25					380.0	459.7	539.3	618.9	698.5	778.1	857.8	937.4	1017.0	1096.6	1176.2	1
26					415.7	502.8	589.9	677.0	764.1	851.2	938.4	1025.5	1112.6	1199.7	1286.8	1
27					452.8	547.7	642.6	737.6	832.5	927.4	1022.3	1117.2	1212.1	1307.0	1401.9	0
28					491.4	594.4	697.5	800.5	903.5	1006.5	1109.5	1212.5	1315.5	1418.5	1521.5	0
29					531.5	642.9	754.3	865.8	977.2	1088.6	1200.0	1311.5	1422.9	1534.3	1645.7	0
30						693.2	813.3	933.5	1053.6	1173.8	1293.9	1414.0	1534.2	1654.3	1774.5	0
31						745.2	874.4	1003.6	1132.7	1261.9	1391.1	1520.3	1649.4	1778.6	1907.8	0
32						799.0	937.5	1076.0	1214.6	1353.1	1491.6	1630.1	1768.6	1907.1	2045.6	0
33						854.6	1002.8	1150.9	1299.1	1447.2	1595.4	1743.6	1891.7	2039.9	2188.0	0
34						912.0	1070.1	1228.2	1386.3	1544.4	1702.5	1860.6	2018.8	2176.9	2335.0	0
35							1139.5	1307.9	1476.2	1644.6	1813.0	1981.4	2149.7	2318.1	2486.5	0
36							1211.0	1389.9	1568.9	1747.8	1926.8	2105.7	2284.7	2463.6	2642.5	0
37							1284.5	1474.4	1664.2	1854.0	2043.8	2233.7	2423.5	2613.3	2803.2	0
38							1360.2	1561.2	1762.2	1963.2	2164.3	2365.3	2566.3	2767.3	2968.3	0
39							1437.9	1650.4	1863.0	2075.5	2288.0	2500.5	2713.0	2925.5	3138.1	0
40								1742.1	1966.4	2190.7	2415.1	2639.4	2863.7	3088.0	3312.3	0
41								1836.1	2072.6	2309.0	2545.4	2781.9	3018.3	3254.7	3491.2	0
42								1932.5	2181.4	2430.3	2679.1	2928.0	3176.8	3425.7	3674.6	0
43								2031.4	2293.0	2554.5	2816.1	3077.7	3339.3	3600.9	3862.5	0
44								2132.6	2407.2	2681.8	2956.5	3231.1	3505.7	3780.4	4055.0	0
45									2524.2	2812.2	3100.1	3388.1	3676.1	3964.1	4252.1	0
46									2643.8	2945.5	3247.1	3548.8	3850.4	4152.0	4453.7	0
47									2766.2	3081.8	3397.4	3713.0	4028.6	4344.2	4659.9	0
48									2891.3	3221.2	3551.0	3880.9	4210.8	4540.7	4870.6	0
49									3019.1	3363.5	3708.0	4052.5	4396.9	4741.4	5085.9	0
50									3149.5	3508.9	3868.3	4227.6	4587.0	4946.3	5305.7	0
BASIS TREES	0	0	13	39	38	36	22	14	4	2	0	0	0	0	0	

BLACKJACK PINE
SANTA FE-CARSON N.F.

PONDEROSA PINE
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.1	.3	.5	.6	.8	1.0	1.1									14
8	.9	2.0	3.0	4.1	5.1	6.2	7.3	8.5								25
9	2.2	4.8	7.4	9.9	12.4	14.9	17.5	20.3	23.1							29
10		8.5	13.1	17.5	21.8	26.2	30.7	35.5	40.5							19
11		13.0	19.9	26.5	33.0	39.5	46.2	53.3	60.8	68.6						27
12		18.1	27.6	36.7	45.6	54.5	63.6	73.3	83.6	94.3						22
13		23.7	36.2	48.1	59.6	70.9	82.7	95.1	108.4	122.4	136.9					27
14		29.9	45.7	60.6	74.8	88.8	103.2	118.6	135.0	152.5	170.6					26
15			55.9	74.0	91.2	107.9	125.2	143.6	163.4	184.4	206.5	229.2				15
16			66.9	88.4	108.7	128.3	148.5	170.0	193.2	218.1	244.3	271.4				13
17			78.7	103.8	127.3	149.9	173.0	197.7	224.6	253.5	284.0	315.6	348.1			14
18			91.2	120.2	147.0	172.8	198.9	226.9	257.4	290.3	325.3	361.8	399.2			15
19			104.5	137.5	167.9	196.8	226.0	257.3	291.6	328.8	368.4	409.8	452.5	496.0		7
20				155.7	189.8	222.0	254.4	289.0	327.1	368.6	413.1	459.6	507.8	556.9		4
21				174.9	212.8	248.3	283.9	322.0	364.0	410.0	459.3	511.2	565.0	620.0	675.9	4
22				195.1	236.9	275.9	314.7	356.3	402.2	452.7	507.1	564.5	624.0	685.1	747.3	1
23				216.2	262.1	304.6	346.7	391.8	441.8	496.9	556.4	619.4	685.0	752.3	821.0	3
24				238.2	288.4	334.5	380.0	428.6	482.6	542.4	607.2	676.0	747.7	821.5	896.9	3
25					315.7	365.5	414.4	466.6	524.7	589.3	659.5	734.1	812.2	892.7	974.9	1
26					344.2	397.7	450.0	505.9	568.1	637.5	713.2	793.9	878.4	965.7	1055.6	1
27					373.7	431.0	486.9	546.4	613.8	687.1	768.3	855.7	946.3	1040.6	1137.2	3
28					404.3	465.6	524.9	588.1	658.8	738.0	824.9	918.1	1016.0	1117.4	1221.4	5
29					436.0	501.3	564.1	631.0	706.9	790.2	882.9	982.5	1087.3	1196.3	1307.7	
30						538.1	604.6	675.2	754.4	843.8	942.3	1048.4	1160.2	1276.4	1395.9	
31						576.1	646.2	720.6	804.7	898.6	1003.1	1115.8	1234.8	1358.6	1486.0	
32						615.3	689.1	767.2	855.1	954.8	1065.3	1184.7	1311.0	1442.5	1578.1	2
33						655.6	733.1	815.0	907.4	1012.3	1128.9	1255.1	1388.8	1528.3	1671.6	1
34						697.1	778.3	864.0	960.8	1071.1	1193.8	1327.0	1468.1	1615.6	1767.9	2
35							824.8	914.3	1015.6	1131.1	1260.1	1400.2	1549.2	1704.8	1865.6	1
36							872.4	965.8	1071.5	1193.5	1327.8	1475.1	1631.7	1795.6	1965.1	
37							921.2	1018.4	1128.7	1255.1	1396.8	1551.3	1715.8	1888.1	2066.5	
38							971.2	1072.3	1187.2	1319.1	1467.2	1629.0	1801.6	1982.4	2169.7	
39							1022.4	1127.5	1246.8	1384.3	1539.0	1708.1	1888.7	2078.1	2274.8	1
40								1183.6	1307.8	1450.8	1612.1	1788.7	1977.3	2175.8	2381.6	
41								1241.3	1369.9	1518.5	1686.5	1870.7	2067.8	2275.1	2491.3	
42								1300.1	1433.2	1587.6	1760.2	1953.1	2159.7	2375.9	2600.6	
43								1360.0	1497.9	1657.9	1839.4	2039.5	2255.6	2478.5	2711.8	
44								1421.2	1563.8	1729.5	1917.8	2125.9	2347.8	2582.6	2826.4	
45									1630.8	1802.4	1997.6	2213.8	2444.1	2688.4	2941.4	
46									1699.1	1876.5	2078.7	2303.8	2542.6	2795.8	3059.9	
47									1748.7	1951.9	2161.1	2394.5	2641.1	2904.9	3179.1	
48									1839.5	2028.6	2244.9	2488.3	2745.1	3021.5	3307.4	
49									1911.5	2106.5	2330.4	2583.8	2845.1	3129.6	3425.1	
50									1984.7	2185.7	2416.4	2677.9	2949.0	3241.7	3548.1	
BASIS TREES	2	10	41	85	141	48	24	14	4	2						

TOTAL STEM GROSS CUBIC FOOT VOLUM -UNBORKED TREES
DOUGLAS-FIR
LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	EXTR
1	.5															0
2	.5	.6														
3	.6	.8	.9													
4	.7	1.0	1.3	1.6												5
5	.9	1.3	1.8	2.2	2.6											5
6	1.1	1.7	2.3	3.0	3.6	4.2										6
7	1.3	2.2	3.0	3.9	4.7	5.6	6.5									7
8	1.6	2.7	3.8	4.9	6.1	7.2	8.3	9.4								7
9	1.9	3.3	4.7	6.1	7.6	9.0	10.4	11.8	13.2							7
10		4.0	5.7	7.5	9.2	11.0	12.7	14.5	16.2							5
11		4.7	6.8	8.9	11.1	13.2	15.3	17.4	19.6	21.7						5
12		5.5	8.0	10.6	13.1	15.6	18.1	20.7	23.2	25.7						6
13		6.4	9.3	12.3	15.3	18.2	21.2	24.2	27.2	30.1	33.1					6
14		7.3	10.8	14.2	17.7	21.1	24.5	28.0	31.4	34.9	38.3					5
15			12.3	16.2	20.2	24.2	28.1	32.1	36.0	40.0	43.9	47.9				5
16			13.9	18.4	22.9	27.4	31.9	36.4	40.9	45.4	49.9	54.4				4
17			15.7	20.7	25.8	30.9	36.0	41.0	46.1	51.2	56.3	61.4	66.4			4
18			17.5	23.2	28.9	34.6	40.3	46.0	51.7	57.3	63.0	68.7	74.4			2
19			19.5	25.8	32.1	38.5	44.8	51.2	57.5	63.8	70.2	76.5	82.9	89.2		3
20				28.5	35.6	42.6	49.6	56.6	63.7	70.7	77.7	84.7	91.8	98.8		3
21				31.4	39.2	46.9	54.7	62.4	70.2	77.9	85.6	93.4	101.1	108.9	116.6	0
22				34.4	42.9	51.4	59.9	68.4	76.9	85.4	94.0	102.5	111.0	119.5	128.0	1
23				37.6	46.9	56.2	65.5	74.8	84.1	93.4	102.6	111.9	121.2	130.5	139.8	5
24				40.9	51.0	61.1	71.3	81.4	91.5	101.6	111.7	121.8	132.0	142.1	152.2	5
25					55.3	66.3	77.3	88.3	99.2	110.2	121.2	132.2	143.1	154.1	165.1	3
26					59.8	71.7	83.6	95.4	107.3	119.2	131.0	142.9	154.8	166.7	178.5	0
27					64.5	77.3	90.1	102.9	115.7	128.5	141.3	154.1	166.9	179.7	192.5	0
28					69.3	83.1	96.8	110.6	124.4	138.1	151.9	165.7	179.5	193.2	207.0	0
29					74.3	89.1	103.8	118.6	133.4	148.2	162.9	177.7	192.5	207.2	222.0	3
30						95.3	111.1	126.9	142.7	158.5	174.3	190.1	205.9	221.7	237.6	0
31						101.7	118.6	135.5	152.4	169.2	186.1	203.0	219.9	236.7	253.6	0
32						108.4	126.3	144.3	162.3	180.3	198.3	216.3	234.3	252.2	270.2	0
33						115.2	134.3	153.5	172.6	191.7	210.8	230.0	249.1	268.2	287.4	1
34						122.3	142.6	162.9	183.2	203.5	223.8	244.1	264.4	284.7	305.0	1
35							151.1	172.6	194.1	215.6	237.1	258.6	280.1	301.7	323.2	3
36							159.8	182.5	205.3	228.1	250.8	273.6	296.4	319.1	341.9	1
37							168.8	192.8	216.8	240.9	264.9	289.0	313.0	337.1	361.1	0
38							178.0	203.3	228.7	254.1	279.4	304.8	330.2	355.5	380.9	0
39							187.4	214.2	240.9	267.6	294.3	321.0	347.7	374.5	401.2	0
40								225.3	253.4	281.5	309.6	337.7	365.8	393.9	422.0	0
41								236.6	266.2	295.7	325.2	354.7	384.3	413.8	443.3	0
42								248.3	279.3	310.3	341.3	372.2	403.2	434.2	465.2	0
43								260.2	292.7	325.2	357.7	390.2	422.6	455.1	487.6	0
44								272.5	306.5	340.5	374.5	408.5	442.5	476.5	510.5	0
45									320.5	356.1	391.7	427.3	462.8	498.4	534.0	0
46									334.9	372.1	409.3	446.4	483.6	520.8	557.9	0
47									349.6	388.4	427.2	466.0	504.8	543.6	582.4	0
48									364.7	405.1	445.6	486.1	526.5	567.0	607.5	0
49									380.0	422.2	464.3	506.5	548.7	590.8	633.0	0
50									395.6	439.5	483.5	527.4	571.3	615.2	659.1	0

DBH CLASS 10 20 30 HEIGHT CLASS

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.5															0
2	.5	.6														0
3	.6	.7	.9													0
4	.7	1.0	1.3	1.5												2
5	.9	1.3	1.7	2.2	2.6											3
6	1.1	1.7	2.3	2.9	3.6	4.2										6
7	1.3	2.1	3.0	3.8	4.7	5.5	6.4									7
8	1.5	2.7	3.8	4.9	6.0	7.1	8.2	9.3								7
9	1.8	3.2	4.7	6.1	7.4	8.8	10.2	11.6	13.0							7
10		3.9	5.6	7.4	9.1	10.8	12.5	14.2	15.9							6
11		4.6	6.7	8.8	10.9	13.0	15.0	17.1	19.1	21.2						5
12		5.4	7.9	10.4	12.9	15.3	17.8	20.3	22.7	25.1						5
13		6.3	9.2	12.1	15.0	17.9	20.8	23.6	26.5	29.3	32.1					4
14		7.2	10.6	14.0	17.3	20.7	24.0	27.3	30.6	33.8	37.0					4
15			12.1	16.0	19.8	23.6	27.4	31.2	34.9	38.6	42.3	45.9				5
16			13.7	18.1	22.5	26.8	31.1	35.4	39.6	43.8	47.9	52.0				7
17			15.4	20.4	25.3	30.1	35.0	39.8	44.5	49.2	53.8	58.4	62.9			6
18			17.2	22.8	28.3	33.7	39.1	44.4	49.7	54.9	60.0	65.1	70.1			5
19			19.1	25.3	31.4	37.4	43.4	49.3	55.1	60.9	66.5	72.1	77.6	83.0		3
20				27.9	34.7	41.4	47.9	54.4	60.8	67.1	73.4	79.5	85.5	91.4		3
21				30.7	38.1	45.5	52.7	59.8	66.8	73.7	80.4	87.1	93.6	100.0	106.4	1
22				33.7	41.8	49.8	57.6	65.4	73.0	80.5	87.8	95.0	102.1	109.0	115.9	1
23				36.7	45.5	54.2	62.8	71.2	79.4	87.5	95.4	103.2	110.8	118.3	125.7	2
24				39.9	49.5	58.9	68.1	77.2	86.1	94.8	103.3	111.6	119.8	127.9	135.8	2
25					53.5	63.7	73.7	83.4	93.0	102.3	111.4	120.4	129.1	137.7	146.1	4
26					57.8	68.7	79.4	89.9	100.1	110.0	119.8	129.3	138.7	147.9	157.0	3
27					62.1	73.9	85.3	96.5	107.4	118.0	128.4	138.5	148.5	158.3	168.0	1
28					66.7	79.2	91.4	103.3	114.9	126.2	137.2	148.0	158.6	169.0	179.4	1
29					71.3	84.7	97.7	110.3	122.6	134.6	146.3	157.7	168.9	180.0	191.	1
30						90.3	104.1	117.5	130.5	143.2	155.5	167.6	179.5	191.	202.9	1
31						96.1	110.8	124.9	138.5	152.0	165.0	177.8	190.4	202.8	215.0	1
32						102.1	117.5	132.5	146.9	161.0	174.7	188.2	201.5	214.7	227.8	1
33						108.2	124.5	140.2	155.4	170.3	184.6	198.8	212.9	226.8	240.7	1
34						114.5	131.6	148.1	164.1	179.6	194.8	209.7	224.5	239.	253.4	1
35							138.8	156.1	172.9	189.2	205.1	220.8	236.4	251.8	267.0	1
36							146.2	164.4	181.9	199.2	215.7	232.2	248.6	264.9	281.1	1
37							153.8	173.7	191.1	208.9	226.5	243.8	261.1	278.3	295.5	1
38							161.5	181.3	200.4	219.1	237.5	255.7	273.8	291.9	311.0	1
39							169.3	189.9	209.9	229.5	248.7	267.8	286.8	305.9	325.0	1
40								198.8	219.6	240.0	260.1	280.1	300.1	320.1	340.1	1
41								207.8	229.5	250.8	271.8	292.8	313.7	334.8	355.9	1
42								216.9	239.5	261.7	283.7	305.7	327.7	349.7	371.9	1
43								226.2	249.8	273.0	295.9	318.9	341.9	365.1	388.3	1
44								235.7	260.2	284.4	308.2	332.1	356.4	380.7	405.1	1
45									270.7	295.9	321.0	346.0	371.0	396.0	421.1	1
46									281.5	307.7	333.8	360.1	386.5	412.9	439.4	1
47									292.4	319.7	347.0	374.4	401.8	429.3	456.8	1
48									303.6	332.0	360.4	389.0	417.9	446.9	476.0	1
49									314.9	344.5	374.1	403.9	434.0	464.4	495.0	1
50									326.5	357.3	388.1	419.2	450.6	482.1	514.0	1
BASI TREES	0	0	10	13	23	26	15	17				1	1			

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNFORKED TREES
DOUGLAS-FIR
LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.7	1.0	1.2	1.5	1.8											1
6	.8	1.3	1.8	2.3	2.8	3.3										5
7	1.0	1.8	2.5	3.3	4.0	4.8	5.5									7
8	1.2	2.2	3.3	4.3	5.3	6.3	7.4	8.4								7
9	1.4	2.8	4.1	5.4	6.8	8.1	9.4	10.8	12.1							7
10		3.3	5.0	6.7	8.4	10.1	11.7	13.4	15.1							6
11		4.0	6.0	8.1	10.1	12.2	14.2	16.3	18.4	20.4						3
12		4.7	7.1	9.6	12.1	14.5	17.0	19.5	21.9	24.4						5
13		5.4	8.3	11.2	14.1	17.1	20.0	22.9	25.8	28.7	31.6					4
14		6.2	9.6	13.0	16.4	19.8	23.2	26.6	29.9	33.3	36.7					5
15			11.0	14.9	18.8	22.7	26.6	30.5	34.4	38.3	42.2	46.1				5
16			12.5	16.9	21.4	25.8	30.3	34.7	39.2	43.6	48.1	52.5				6
17			14.0	19.1	24.1	29.1	34.2	39.2	44.2	49.3	54.3	59.3	64.3			4
18			15.7	21.4	27.0	32.7	38.3	43.9	49.6	55.2	60.9	66.5	72.2			2
19			17.5	23.8	30.1	36.4	42.7	49.0	55.3	61.6	67.9	74.2	80.5	86.8		5
20				26.3	33.3	40.3	47.3	54.2	61.2	68.2	75.2	82.2	89.2	96.2		3
21				29.0	36.7	44.4	52.1	59.8	67.5	75.2	82.9	90.6	98.3	106.1	113.8	0
22				31.8	40.2	48.7	57.2	65.6	74.1	82.6	91.0	99.5	108.0	116.4	124.9	1
23				34.7	43.9	53.2	62.5	71.7	81.0	90.2	99.5	108.7	118.0	127.3	136.5	5
24				37.7	47.8	57.9	68.0	78.1	88.2	98.2	108.3	118.4	128.5	138.6	148.7	5
25					51.9	62.8	73.8	84.7	95.7	106.6	117.5	128.5	139.4	150.4	161.3	3
26					56.1	67.9	79.8	91.6	103.5	115.3	127.1	139.0	150.8	162.7	174.5	0
27					60.4	73.2	86.0	98.8	111.6	124.3	137.1	149.9	162.7	175.4	188.2	0
28					65.0	78.7	92.5	106.2	120.0	133.7	147.4	161.2	174.9	188.7	202.4	0
29					69.7	84.4	99.2	113.9	128.7	143.4	158.2	172.9	187.6	202.4	217.1	3
30						90.3	106.1	121.9	137.7	153.5	169.2	185.0	200.8	216.6	232.4	0
31						96.4	113.3	130.1	147.0	163.9	180.7	197.6	214.4	231.3	248.1	0
32						102.7	120.7	138.7	156.6	174.6	192.5	210.5	228.5	246.4	264.4	0
33						109.2	128.3	147.5	166.6	185.7	204.8	223.9	243.0	262.1	281.2	1
34						115.9	136.2	156.5	176.8	197.1	217.4	237.6	257.9	278.2	298.5	1
35							144.3	165.8	187.3	208.8	230.3	251.8	273.3	294.8	316.3	3
36							152.7	175.4	198.2	220.9	243.7	266.4	289.1	311.9	334.6	1
37							161.3	185.3	209.3	233.3	257.4	281.4	305.4	329.4	353.5	0
38							170.1	195.4	220.8	246.1	271.5	296.8	322.1	347.5	372.8	0
39							179.1	205.8	232.5	259.2	285.9	312.6	339.3	366.0	392.7	0
40								216.5	244.6	272.7	300.8	328.9	356.9	385.0	413.1	0
41								227.5	257.0	286.5	316.0	345.5	375.0	404.5	434.0	0
42								238.7	269.6	300.6	331.6	362.5	393.5	424.5	455.4	0
43								250.2	282.6	315.1	347.5	380.0	412.5	444.9	477.4	0
44								261.9	295.9	329.9	363.9	397.9	431.9	465.8	499.8	0
45									309.5	345.1	380.6	416.2	451.7	487.3	522.8	0
46									323.4	360.5	397.7	434.8	472.0	509.1	546.3	0
47									337.6	376.4	415.2	453.9	492.7	531.5	570.3	0
48									352.1	392.6	433.0	473.5	513.9	554.4	594.8	0
49									366.9	409.1	451.2	493.4	535.5	577.7	619.9	0
50									382.0	425.9	469.8	513.7	557.6	601.5	645.4	0
BASIS TREES	0	0	1	13	33	33	13	8	5	7	2	1	1	0	0	

LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.7	.9	1.2	1.5	1.8											3
6	.8	1.3	1.8	2.3	2.8	3.3										5
7	1.0	1.7	2.5	3.2	3.9	4.7	5.4									7
8	1.2	2.2	3.2	4.2	5.2	6.2	7.2	8.2								7
9	1.4	2.7	4.0	5.4	6.7	8.0	9.3	10.6	11.9							7
10		3.3	5.0	6.6	8.2	9.9	11.5	13.2	14.8							4
11		3.9	5.9	8.0	10.0	12.0	14.0	16.0	17.9	19.9						
12		4.6	7.0	9.5	11.9	14.3	16.6	19.0	21.4	23.7						5
13		5.4	8.2	11.1	13.9	16.7	19.5	22.3	25.1	27.9	30.6					5
14		6.2	9.5	12.8	16.1	19.4	22.6	25.9	29.1	32.3	35.5					5
15			10.8	14.6	18.4	22.2	26.0	29.7	33.4	37.0	40.6	44.2				4
16			12.3	16.6	20.9	25.2	29.5	33.7	37.9	42.0	46.1	50.2				7
17			13.8	18.7	23.6	28.4	33.2	38.0	42.7	47.3	51.9	56.5	61.0			4
18			15.4	20.9	26.4	31.8	37.2	42.5	47.7	52.9	58.0	63.0	68.0			3
19			17.2	23.3	29.3	35.4	41.2	47.2	53.0	58.7	64.4	69.9	75.4	80.9		4
20				25.7	32.5	39.1	45.7	52.1	58.5	64.8	71.0	77.1	83.2	89.1		3
21				28.3	35.7	43.0	50.2	57.3	64.3	71.3	78.0	84.6	91.2	97.6	104.1	1
22				31.0	39.1	47.1	55.0	62.7	70.3	77.8	85.2	92.4	99.5	106.5	113.4	1
23				33.8	42.7	51.3	59.9	68.3	76.6	84.7	92.6	100.4	108.1	115.6	123.1	1
24				36.8	46.4	55.8	65.0	74.1	83.0	91.8	100.3	108.7	117.	125.2	133.1	
25					50.2	60.4	70.4	80.1	89.7	99.1	108.3	117.3	126.1	134.8	143.4	1
26					54.2	65.1	75.9	86.4	96.6	106.6	116.5	126.1	135.5	144.8	154.1	
27					58.3	70.0	81.5	92.8	103.7	114.4	124.9	135.1	145.1	155.1	164.9	
28					62.5	75.1	87.4	99.4	111.0	122.4	133.5	144.4	155.1	165.7	176.1	
29					66.9	80.3	93.4	106.1	118.5	130.6	142.4	153.9	165.4	176.5	187.6	1
30						85.7	99.6	113.1	126.2	139.1	151.5	163.7	175.7	187.6	199.4	
31						91.3	106.2	120.7	134.1	147.4	160.4	173.2	186.4	199.		
32						96.9	112.5	127.5	142.2	156.4	170.3	183.9	197.3			.8
33						102.8	119.0	135.0	150.4	165.4	180.	194.3	208.4		236.3	
34						108.7	125.6	142.7	158.8	174.5	189.9	205.	219.9		249.5	
35							132.3	150.4	167.4	183.9	200.4	215.9	231.6			
36							139.1	158.4	176.1	193.4	210.3	226.	241.6	256.		
37							147.2	166.5	185.1	203.1	220.9	238.4	255.8	273.		
38							154.7	174.8	194.2	213.1	231.6	250.	268.	286.		.6
39							162.3	183.1	203.4	223.2	242.6	261.8	281.			
40								191.7	212.8	233.4	253.8	273.9	294.			
41								200.4	222.4	243.9	265.1	286.				
42								209.3	232.1	254.6	276.7	298.5	320.2			
43								218.2	242.1	265.4	288.7					
44								227.4	252.3	276.5	300.6					
45									262.8	288.0	313.0					
46									273.8	299.9	325.9					
47									284.9	312.0	338.9					
48									296.3	324.5	352.5					
49									307.9	337.2	366.3					
50									319.8	350.1	380.2					
ALL TREES																

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES-UNFORKED TREES
DOUGLAS-FIR
LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.7	1.2	1.7	2.2	2.7	3.2	3.6									7
8	1.0	1.8	2.6	3.4	4.1	4.9	5.7	6.5								7
9	1.2	2.3	3.5	4.6	5.7	6.9	8.0	9.1	10.3							7
10		3.0	4.5	6.0	7.4	8.9	10.4	11.9	13.4							6
11		3.6	5.5	7.4	9.3	11.2	13.1	15.0	16.8	18.7						9
12		4.4	6.7	9.0	11.3	13.6	15.9	18.2	20.5	22.8						5
13		5.1	7.9	10.7	13.4	16.2	19.0	21.7	24.5	27.3	30.0					6
14		6.0	9.2	12.5	15.7	19.0	22.2	25.5	28.8	32.0	35.3					5
15			10.6	14.4	18.2	22.0	25.7	29.5	33.3	37.1	40.8	44.6				5
16			12.1	16.5	20.8	25.1	29.5	33.8	38.1	42.5	46.8	51.1				6
17			13.7	18.6	23.6	28.5	33.4	38.3	43.2	48.2	53.1	58.0	62.9			4
18			15.4	20.9	26.5	32.0	37.6	43.1	48.7	54.2	59.8	65.3	70.8			2
19			17.2	23.4	29.6	35.8	42.0	48.2	54.4	60.6	66.8	73.0	79.2	85.4		5
20				25.9	32.8	39.7	46.6	53.5	60.4	67.3	74.2	81.1	88.0	94.9		3
21				28.6	36.2	43.9	51.5	59.1	66.7	74.3	82.0	89.6	97.2	104.8	112.4	0
22				31.4	39.8	48.2	56.6	65.0	73.3	81.7	90.1	98.5	106.9	115.2	123.6	1
23				34.4	43.5	52.7	61.9	71.1	80.2	89.4	98.6	107.8	117.0	126.1	135.3	5
24				37.4	47.4	57.4	67.5	77.5	87.5	97.5	107.5	117.5	127.5	137.5	147.5	5
25					51.5	62.4	73.2	84.1	95.0	105.9	116.7	127.6	138.5	149.3	160.2	3
26					55.7	67.5	79.3	91.0	102.8	114.6	126.4	138.1	149.9	161.7	173.4	0
27					60.1	72.8	85.5	98.2	110.9	123.6	136.3	149.1	161.8	174.5	187.2	0
28					64.7	78.3	92.0	105.7	119.4	133.0	146.7	160.4	174.1	187.7	201.4	0
29					69.4	84.0	98.7	113.4	128.1	142.8	157.5	172.1	186.8	201.5	216.2	3
30						90.0	105.7	121.4	137.1	152.8	168.6	184.3	200.0	215.7	231.4	0
31						96.1	112.9	129.7	146.5	163.3	180.1	196.8	213.6	230.4	247.2	0
32						102.4	120.3	138.2	156.1	174.0	191.9	209.8	227.7	245.6	263.5	0
33						108.9	128.0	147.0	166.1	185.1	204.1	223.2	242.2	261.3	280.3	1
34						115.6	135.8	156.1	176.3	196.5	216.8	237.0	257.2	277.4	297.7	1
35							144.0	165.4	186.9	208.3	229.7	251.2	272.6	294.1	315.5	3
36							152.3	175.0	197.7	220.4	243.1	265.8	288.5	311.2	333.9	1
37							160.9	184.9	208.9	232.8	256.8	280.8	304.8	328.7	352.7	0
38							169.8	195.0	220.3	245.6	270.9	296.2	321.5	346.8	372.1	0
39							178.8	205.5	232.1	258.8	285.4	312.1	338.7	365.4	392.0	0
40								216.1	244.2	272.2	300.3	328.3	356.3	384.4	412.4	0
41								227.1	256.6	286.0	315.5	345.0	374.4	403.9	433.3	0
42								238.3	269.3	300.2	331.1	362.0	392.9	423.9	454.8	0
43								249.8	282.2	314.7	347.1	379.5	411.9	444.3	476.7	0
44								261.6	295.5	329.5	363.4	397.4	431.3	465.3	499.2	0
45									309.1	344.6	380.2	415.7	451.2	486.7	522.2	0
46									323.0	360.1	397.3	434.4	471.5	508.6	545.7	0
47									337.2	376.0	414.7	453.5	492.2	531.0	569.7	0
48									351.8	392.2	432.6	473.0	513.4	553.8	594.2	0
49									366.6	408.7	450.8	492.9	535.0	577.2	619.3	0
50									381.7	425.6	469.4	513.3	557.1	601.0	644.8	0
BASIS TREES	0	0	0	13	23	23	15	8	5	7	2	1	1	0	0	

DOUGLAS-FIR
LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.7	1.2	1.7	2.2	2.6	3.1	3.6									7
8	1.0	1.7	2.5	3.3	4.1	4.9	5.6	6.4								7
9	1.2	2.3	3.4	4.5	5.6	6.8	7.9	9.0	10.0							7
10		2.9	4.4	5.9	7.3	8.8	10.2	11.7	13.1							8
11		3.6	5.4	7.3	9.1	11.0	12.8	14.6	16.4	18.3						9
12		4.3	6.6	8.8	11.1	13.3	15.6	17.8	20.0	22.2						11
13		5.1	7.8	10.5	13.2	15.9	18.5	21.2	23.8	26.5	29.1					11
14		5.9	9.1	12.3	15.4	18.6	21.7	24.8	27.9	31.0	34.0					8
15			10.5	14.1	17.8	21.5	25.1	28.7	32.2	35.8	39.3	42.8				6
16			11.9	16.2	20.4	24.5	28.7	32.8	36.8	40.9	44.8	48.8				7
17			13.5	18.3	23.0	27.8	32.4	37.1	41.7	46.2	50.7	55.1	59.5			8
18			15.1	20.5	25.9	31.2	36.4	41.6	46.8	51.8	56.8	61.8	66.7			8
19			16.9	22.9	28.8	34.8	40.6	46.4	52.1	57.7	63.3	68.7	74.1	79.5		8
20				25.4	32.0	38.5	45.0	51.4	57.7	63.9	70.1	76.2	81.9	87.7		9
21				28.0	35.3	42.4	49.6	56.6	63.5	70.3	76.9	83.5	90.2	96.3	102.6	12
22				30.7	38.7	46.6	54.2	62.0	69.5	76.9	84.2	91.3	98.3	105.2	111.0	11
23				33.5	42.2	50.8	59.3	67.6	75.8	83.8	91.7	99.4	107.1	114.4	121.8	9
24				36.4	45.9	55.3	64.4	73.4	82.3	90.9	99.4	107.7	115.9	124.9	131.8	9
25					49.8	59.9	69.8	79.5	89.0	98.2	107.4	116.3	125.1	133.7	142.2	9
26					53.8	64.6	75.3	85.7	95.9	105.8	115.6	125.1	134.5	143.7	152.8	11
27					57.9	69.5	81.0	92.1	103.0	113.6	124.0	134.0	144.0	154.1	163.8	11
28					62.1	74.7	86.9	98.7	110.3	121.6	132.7	143.6	154.4	165.1	175.	9
29					66.6	79.9	92.9	105.4	117.9	129.9	141.6	153.2	164.6	175.5	186.6	9
30						85.3	99.1	112.4	125.6	138.3	150.7	162.9	174.8	186.7	198.4	11
31						90.8	105.5	119.7	133.5	146.9	160.	172.9	185.5	198.1	211.5	11
32						96.5	112.0	127.0	141.5	155.7	169.5	183.1	196.5	209.8	222.9	9
33						102.3	118.7	134.5	149.8	164.7	179.3	193.6	207.7	221.6	235.	5
34						108.3	125.5	142.1	158.2	173.9	189.3	204.4	219.	234.0	248.7	6
35							132.5	150.0	166.8	183.3	199.5	215.	230.9	246.5	262.	6
36							139.6	157.8	175.6	193.0	209.9	226.6	243.0	259.	275.	7
37							146.9	166.	184.5	202.6	220.3	237.8	255.	272.1	289.0	6
38							154.3	174.3	193.6	212.6	231.2	249.6	267.6	285.5	303.0	9
39							161.8	182.7	202.9	222.6	242.	261.	280.	298.5	316.8	6
40								191.2	212.4	233.0	253.4	273.4	293.4	312.9	332.3	5
41								200.0	222.1	243.6	264.9	285.9	306.7	327.4	347.8	6
42								208.8	231.7	254.1	276.	298.	320.	341.8	363.3	6
43								217.8	241.6	265.	288.1	311.1	334.2	357.1	379.8	6
44								227.0	251.7	276.	300.3	324.2	348.1	371.9	395.6	6
45									262.	287.4	312.6	337.5	362.4	387.1	411.8	6
46									272.4	298.8	325.1	351.1	376.9	402.6	428.2	6
47									282.9	310.4	337.8	365.0	391.8	418.4	445.0	6
48									293.6	322.2	350.6	379.0	407.0	434.6	462.4	6
49									304.5	334.2	363.8	393.3	422.4	451.2	480.1	6
50									315.9	346.7	377.5	408.2	438.2	468.2	498.1	6

GROSS INTERNATIONAL BOARD FOOT VOLUME TO A INCH TOP DIB-UNFORKED TREES
DOUGLAS-FIR
LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	1.1	1.8	2.5	3.3	4.0	4.7	5.4									7
8	2.6	4.7	6.8	9.0	11.1	13.2	15.3	17.5								7
9	4.2	8.2	12.1	16.0	20.0	23.9	27.8	31.8	35.7							7
10		12.1	18.1	24.2	30.2	36.3	42.4	48.4	54.5							6
11		16.3	24.8	33.3	41.8	50.2	58.7	67.2	75.7	84.1						8
12		21.0	32.2	43.3	54.4	65.6	76.7	87.9	99.0	110.1						5
13		26.1	40.1	54.2	68.2	82.3	96.3	110.4	124.4	138.4	152.5					4
14		31.5	48.7	65.9	83.1	100.3	117.5	134.6	151.8	169.0	186.2					5
15			57.9	78.5	99.0	119.6	140.2	160.7	181.3	201.8	222.4	243.0				5
16			67.7	91.9	116.0	140.2	164.4	188.6	212.7	236.9	261.1	285.3				5
17			78.1	106.1	134.1	162.1	190.1	218.2	246.2	274.2	302.2	330.2	358.2			4
18			89.1	121.2	153.3	185.4	217.4	249.5	281.6	313.7	345.8	377.8	409.9			2
19			100.7	137.1	173.5	209.9	246.3	282.6	319.0	355.4	391.8	428.2	464.5	500.9		5
20				153.9	194.8	235.7	276.6	317.5	358.4	399.3	440.2	481.1	522.1	563.0		3
21				171.5	217.1	262.8	308.5	354.1	399.8	445.5	491.1	536.8	582.5	628.1	673.8	0
22				189.9	240.6	291.2	341.9	392.5	443.2	493.8	544.5	595.2	645.8	696.5	747.1	1
23				209.2	265.1	321.0	376.8	432.7	488.6	544.4	600.3	656.2	712.1	767.9	823.8	5
24				229.3	290.7	352.0	413.3	474.6	535.9	597.3	658.6	719.9	781.2	842.5	903.9	5
25					317.3	384.3	451.3	518.3	585.3	652.3	719.3	786.3	853.3	920.3	987.3	3
26					345.1	418.0	490.9	563.8	636.7	709.6	782.5	855.4	928.3	1001.2	1074.1	0
27					373.9	452.9	532.0	611.0	690.0	769.1	848.1	927.2	1006.2	1085.2	1164.2	0
28					403.8	489.2	574.6	660.0	745.4	830.8	916.2	1001.6	1087.0	1172.4	1257.8	0
29					434.7	526.7	618.7	710.8	802.8	894.8	986.8	1078.8	1170.8	1262.8	1354.8	2
30						565.6	664.5	763.3	862.1	961.0	1059.8	1158.6	1257.4	1356.2	1455.1	0
31						605.8	711.7	817.6	923.5	1029.4	1135.3	1241.2	1347.0	1452.9	1558.8	0
32						647.3	760.5	873.7	986.8	1100.0	1213.2	1326.4	1439.6	1552.7	1665.9	0
33						690.1	810.8	931.5	1052.2	1172.9	1293.6	1414.3	1535.0	1655.7	1776.4	1
34						734.2	862.7	991.1	1119.6	1248.0	1376.5	1504.9	1633.4	1761.8	1890.3	1
35							916.1	1052.5	1189.0	1325.4	1461.8	1598.3	1734.7	1871.1	2007.5	3
36							971.1	1115.7	1260.3	1405.0	1549.6	1694.3	1838.9	1983.6	2128.2	1
37							1027.6	1180.6	1333.7	1486.8	1639.9	1793.0	1946.1	2099.2	2252.2	0
38							1085.6	1247.4	1409.1	1570.9	1732.6	1894.4	2056.2	2217.9	2379.7	0
39							1145.2	1315.9	1486.5	1657.2	1827.8	1998.5	2169.2	2339.8	2510.5	0
40								1386.1	1565.9	1745.7	1925.5	2105.3	2285.1	2464.9	2644.7	0
41								1458.2	1647.3	1836.5	2025.7	2214.8	2404.0	2593.2	2782.3	0
42								1532.0	1730.8	1929.5	2128.3	2327.0	2525.8	2724.6	2923.3	0
43								1607.6	1816.2	2024.8	2233.4	2442.0	2650.5	2859.1	3067.7	0
44								1685.0	1903.6	2122.3	2340.9	2559.6	2778.2	2996.9	3215.5	0
45									1993.1	2222.0	2450.9	2679.9	2908.8	3137.7	3366.7	0
46									2084.5	2324.0	2563.4	2802.9	3042.3	3281.8	3521.3	0
47									2178.0	2428.2	2678.4	2928.6	3178.8	3429.0	3679.2	0
48									2273.4	2534.6	2795.8	3057.0	3318.2	3579.4	3840.6	0
49									2370.9	2643.3	2915.7	3188.1	3460.5	3733.0	4005.4	0
50									2470.4	2754.3	3038.1	3322.0	3605.8	3889.7	4173.5	0
BASIS TREES	0	0	4	13	23	23	15	8	5	7	2	1	1	0	0	

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	1.0	1.7	2.5	3.2	3.9	4.7	5.4									7
8	2.3	4.4	6.5	8.6	10.8	13.0	15.1	17.3								7
9	3.6	7.3	11.2	15.1	19.2	23.2	27.2	31.3	35.3							7
10		10.3	16.1	22.2	28.4	34.7	40.9	47.2	53.5							6
11		13.2	21.1	29.5	38.1	46.9	55.7	64.6	73.4	82.2						5
12		15.9	26.0	36.8	48.0	59.5	71.1	82.8	94.6	106.3						6
13		18.2	30.5	43.8	57.8	72.2	86.9	101.7	116.6	131.5	146.4					4
14		20.3	34.7	50.5	67.3	84.8	102.7	121.0	139.3	157.7	176.1					4
15			38.5	56.8	76.5	97.2	118.6	140.3	162.4	184.5	206.7	228.8				5
16			42.0	62.8	85.5	109.5	134.3	159.8	185.7	211.9	238.1	264.3				4
17			45.4	68.7	94.3	121.6	150.1	179.5	209.4	239.7	270.2	300.8	331.3			4
18			48.8	74.6	103.2	133.8	166.1	199.4	233.5	268.1	303.1	338.2	373.2			2
19			52.3	80.5	112.1	146.2	182.2	219.6	258.0	297.1	336.6	376.5	416.5	456.5		2
20				86.6	121.2	158.8	198.6	240.1	282.9	326.6	371.0	415.7	460.7	505.8		3
21				92.9	130.6	171.6	215.3	261.1	308.4	356.8	406.1	455.9	506.1	556.5	606.9	1
22				99.4	140.2	184.8	232.5	282.5	334.4	387.7	442.0	497.1	552.6	608.4	664.4	1
23				106.1	150.0	198.3	250.0	304.4	361.0	419.2	478.7	539.1	600.1	661.6	723.4	1
24				113.1	160.2	212.1	267.9	326.7	388.1	451.3	516.1	582.0	648.7	716.0	783.7	1
25					170.6	226.2	286.1	349.5	415.7	484.1	554.3	625.8	698.2	771.6	845.3	1
26					181.3	240.7	304.8	372.7	443.9	517.5	593.2	671.4	748.9	826.7	904.8	1
27					192.0	255.4	323.8	396.4	472.5	551.5	632.8	715.9	801.4	886.9	972.5	1
28					203.4	270.5	343.1	420.5	501.7	586.7	673.0	761.1	852.8	944.8	1037.8	1
29					214.8	285.8	362.8	444.9	531.3	621.1	713.9	809.4	906.1	1004.6	1104.4	1
30						301.3	382.8	469.7	561.3	656.8	755.4	856.7	960.2	1065.4	1172.1	1
31						317.2	403.1	494.9	591.8	692.9	797.5	905.1	1015.1	1127.1	1241.1	1
32						333.3	423.7	520.5	622.7	729.5	840.3	954.3	1071.8	1189.7	1311.4	1
33						349.6	444.6	546.4	654.1	766.7	883.5	1003.9	1127.3	1254.1	1381.1	1
34						366.1	465.8	572.7	685.8	804.3	927.3	1054.1	1184.5	1317.5	1453.8	1
35							487.3	599.3	717.9	842.3	971.2	1105.4	1242.4	1382.2	1525.4	1
36							509.0	626.2	750.4	880.8	1016.6	1156.9	1301.1	1448.6	1599.2	1
37							531.1	653.4	783.2	919.8	1062.2	1209.1	1360.4	1515.2	1674.4	1
38							553.3	681.0	816.4	959.2	1107.9	1261.8	1420.4	1582.8	1748.8	1
39							575.8	708.8	850.0	999.0	1154.2	1315.2	1481.1	1651.0	1824.8	1
40								737.1	884.2	1039.3	1201.2	1369.1	1542.4	1719.7	1901.6	1
41								765.5	918.6	1080.4	1248.4	1423.6	1603.4	1789.0	1979.0	1
42								794.2	953.4	1121.4	1296.4	1478.6	1666.3	1858.9	2056.8	1
43								823.4	988.4	1163.5	1344.8	1534.1	1729.9	1929.4	2135.5	1
44								852.8	1023.9	1204.9	1393.6	1590.2	1793.1	2000.7	2214.8	1
45									1059.7	1246.8	1442.8	1646.9	1858.1	2073.5	2295.8	1
46									1095.8	1289.5	1492.6	1704.1	1923.9	2148.6	2378.1	1
47									1132.3	1332.6	1542.7	1761.4	1988.5	2220.7	2460.5	1
48									1169.2	1376.1	1593.4	1819.8	2053.6	2294.4	2543.4	1
49									1206.3	1419.8	1644.5	1878.8	2121.4	2369.0	2626.9	1
50									1243.9	1464.4	1695.9	1937.7	2188.5	2444.5	2711.6	1

BASIS																
TREES	2	6	4	13	13	15	15	9	7	7	3	1	1			

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNFORKED TREES
DOUGLAS-FIR
LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.6	1.1	1.5	1.9	2.3	2.8	3.2									0
8	1.7	3.0	4.4	5.8	7.2	8.5	9.9	11.3								0
9	2.9	5.7	8.4	11.1	13.8	16.6	19.3	22.0	24.7							5
10		8.8	13.2	17.6	22.0	26.5	30.9	35.3	39.7							6
11		12.4	18.8	25.2	31.6	38.1	44.5	50.9	57.3	63.7						5
12		16.4	25.1	33.8	42.5	51.2	59.9	68.6	77.3	86.0						5
13		20.9	32.1	43.4	54.6	65.9	77.1	88.4	99.6	110.9	122.1					5
14		25.8	39.8	53.9	67.9	82.0	96.0	110.1	124.2	138.2	152.3					5
15			48.2	65.3	82.4	99.5	116.6	133.7	150.8	167.9	185.0	202.2				5
16			57.2	77.6	98.0	118.4	138.8	159.2	179.6	200.0	220.4	240.9				5
17			66.8	90.7	114.7	138.6	162.6	186.6	210.5	234.5	258.4	282.4	306.3			4
18			77.0	104.8	132.5	160.3	188.0	215.7	243.5	271.2	299.0	326.7	354.4			2
19			87.9	119.7	151.5	183.2	215.0	246.7	278.5	310.3	342.0	373.8	405.6	437.3		5
20				135.5	171.5	207.5	243.6	279.6	315.6	351.6	387.6	423.7	459.7	495.7		3
21				152.1	192.7	233.2	273.7	314.2	354.7	395.2	435.8	476.3	516.8	557.3	597.8	0
22				169.7	214.9	260.2	305.4	350.7	395.9	441.2	486.4	531.7	576.9	622.2	667.4	1
23				188.0	238.3	288.5	338.7	388.9	439.1	489.3	539.6	589.8	640.0	690.2	740.4	5
24				207.3	262.7	318.1	373.5	429.0	484.4	539.8	595.2	650.6	706.1	761.5	816.9	5
25					288.2	349.1	410.0	470.8	531.7	592.5	653.4	714.2	775.1	835.9	896.8	3
26					314.9	381.4	447.9	514.5	581.0	647.5	714.0	780.6	847.1	913.6	980.1	0
27					342.6	415.0	487.5	559.9	632.3	704.8	777.2	849.6	922.0	994.5	1066.9	0
28					371.4	450.0	528.6	607.1	685.7	764.3	842.8	921.4	1000.0	1078.5	1157.1	0
29					401.3	486.3	571.2	656.2	741.1	826.0	911.0	995.9	1080.8	1165.8	1250.7	3
30						523.9	615.4	707.0	798.5	890.1	981.6	1073.1	1164.7	1256.2	1347.8	0
31						562.8	661.2	759.6	858.0	956.3	1054.7	1153.1	1251.5	1349.9	1448.2	0
32						603.1	708.5	814.0	919.4	1024.9	1130.3	1235.8	1341.2	1446.7	1552.1	0
33						644.7	757.4	870.2	982.9	1095.7	1208.4	1321.2	1433.9	1546.7	1659.5	1
34						687.6	807.9	928.2	1048.5	1168.7	1289.0	1409.3	1529.6	1649.9	1770.2	1
35							859.9	987.9	1116.0	1244.1	1372.1	1500.2	1628.2	1756.3	1884.3	3
36							913.4	1049.5	1185.6	1321.6	1457.7	1593.7	1729.8	1865.9	2001.9	1
37							968.6	1112.8	1257.1	1401.4	1545.7	1690.0	1834.3	1978.6	2122.9	0
38							1025.2	1178.0	1330.7	1483.5	1636.3	1789.0	1941.8	2094.5	2247.3	0
39							1083.5	1244.9	1406.4	1567.8	1729.3	1890.8	2052.2	2213.7	2375.1	0
40								1313.6	1484.0	1654.4	1824.8	1995.2	2165.6	2336.0	2506.4	0
41								1384.1	1563.7	1743.2	1922.8	2102.4	2281.9	2461.5	2641.0	0
42								1456.4	1645.4	1834.3	2023.3	2212.2	2401.2	2590.1	2779.1	0
43								1530.5	1729.1	1927.7	2126.2	2324.8	2523.4	2722.0	2920.6	0
44								1606.4	1814.8	2023.2	2231.7	2440.1	2648.6	2857.0	3065.5	0
45									1902.5	2121.1	2339.6	2558.2	2776.7	2995.2	3213.8	0
46									1992.3	2221.2	2450.0	2678.9	2907.8	3136.6	3365.5	0
47									2084.1	2323.5	2562.9	2802.4	3041.8	3281.2	3520.6	0
48									2177.9	2428.1	2678.3	2928.5	3178.8	3429.0	3679.2	0
49									2273.7	2535.0	2796.2	3057.4	3318.7	3579.9	3841.1	0
50									2371.6	2644.0	2916.5	3189.0	3461.5	3734.0	4006.5	0
BASIS TREES	0	0	0	5	16	23	15	8	5	7	2	1	1	0	0	

NET SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB
DOUGLAS-FIR
LINCOLN-TONTO N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.6	1.0	1.4	1.9	2.3	2.7	3.2									7
8	1.4	2.7	4.1	5.6	7.0	8.4	9.8	11.2								-
9	2.3	4.9	7.6	10.4	13.2	16.0	18.9	21.7	24.5							7
10		7.1	11.4	15.9	20.5	25.2	29.8	34.4	39.0							-
11		9.2	15.2	21.7	28.4	35.2	42.1	48.9	55.7	62.4						-
12		11.0	18.9	27.5	36.6	45.8	55.2	64.6	73.9	83.2						2
13		12.3	22.0	32.9	44.5	56.6	68.8	81.0	93.3	105.5	117.6					-
14		13.2	24.6	37.8	52.1	67.1	82.4	97.9	113.4	128.8	144.2					-
15			26.7	42.1	59.2	77.2	95.9	114.8	133.9	153.0	171.9	190.8				-
16			28.1	45.8	65.6	86.9	109.0	131.7	154.6	177.4	200.5	223.3				-
17			29.1	49.0	71.6	96.2	121.9	148.5	175.4	202.6	229.7	256.8	283.7			1
18			29.9	51.8	77.2	105.0	134.5	165.1	196.3	227.8	259.5	291.1	322.5			2
19			30.3	54.3	82.5	113.6	146.9	181.6	217.2	253.3	289.7	326.1	361.4	398.5		-
20				56.7	87.6	122.0	159.1	198.0	238.1	279.0	320.3	361.7	403.1	444.4		-
21				58.9	92.5	130.3	171.2	214.4	259.1	304.9	351.2	397.9	444.6	491.3	537.8	1
22				61.0	97.2	138.4	183.2	230.7	280.2	330.9	382.5	434.6	486.9	539.2	591.3	1
23				63.0	101.9	146.4	195.1	247.0	301.2	357.1	414.1	471.7	529.7	587.9	646.0	-
24				64.9	106.4	154.2	206.9	263.2	322.2	382.4	445.8	509.2	573.2	637.4	701.6	5
25					110.9	162.0	218.6	279.2	343.3	409.7	477.8	547.2	617.1	687.5	758.1	3
26					115.2	169.6	230.1	295.4	364.3	436.0	509.8	585.1	661.3	738.2	815.3	-
27					119.3	177.0	241.4	311.2	385.2	461.4	543.0	623.3	704.9	789.4	873.3	-
28					123.3	184.2	252.6	326.9	405.9	488.6	574.1	661.7	750.8	841.1	931.8	-
29					127.1	191.3	263.6	342.4	426.5	514.7	606.2	700.1	795.8	892.9	99 .8	-
30						198.1	274.3	357.7	446.9	540.7	638.3	738.5	841.1	945.1	1051.	-
31						204.7	284.8	372.7	467.1	566.5	670.1	776.9	886.1	997.4	1111.1	-
32						211.0	295.0	387.5	487.0	592.1	701.9	815.4	931.5	1049.9	1171.	-
33						217.2	305.0	402.0	506.7	617.5	733.4	853.4	976.7	1100.5	1225.	-
34						223.0	314.7	416.3	526.2	642.6	764.8	891.5	1021.8	1152.1	1284.5	-
35							324.1	430.2	545.1	667.4	795.9	929.1	1066.8	1207.6	1351.	-
36							333.2	443.8	563.9	690.9	826.7	966.9	1111.1	1260.1	1411.4	1
37							342.0	457.1	582.3	716.2	857.7	1004.4	1156.4	1310.1	1471.8	-
38							350.5	470.0	600.4	741.0	887.4	1041.4	1200.8	1364.1	1531.	-
39							358.6	482.6	618.1	765.5	917.3	1078.1	1245.1	1416.1	1589.	-
40								494.8	635.6	786.7	946.8	1114.6	1288.8	1468.4	1649.5	-
41								506.7	652.5	809.9	976.1	1151.2	1331.4	1517.6	1710.4	-
42								518.3	669.1	831.8	1004.8	1186.5	1375.7	1571.	1771.	-
43								529.4	685.4	853.8	1033.2	1221.8	1418.6	1624.1	1831.5	-
44								540.2	701.2	875.4	1061.1	1256.8	1461.1	1677.	1894.	-
45									716.6	896.6	1088.7	1291.4	1504.1	1729.	1956.9	-
46									731.7	917.3	1115.8	1325.5	1545.	1779.8	2018.6	-
47									746.3	937.6	1142.5	1359.	1586.4	1831.	2081.	-
48									760.5	957.5	1168.7	1391.4	1627.1	1881.5	2142.9	-
49									774.2	976.9	1194.5	1425.2	1667.5	1931.	2203.	-
50									787.6	995.9	1219.8	1457.6	1707.5	1980.	2264.	-
BASIS TREES	5	5	4	13	21	25	15	5	5	1	1	1	1	1	1	

TOTAL STEM GROSS CUBIC FOOT VOLUME-UNFORKED TREES
DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.4															0
2	.4	.5														2
3	.5	.7	.9													3
4	.6	1.0	1.3	1.6												4
5	.8	1.3	1.8	2.3	2.7											3
6	1.0	1.7	2.4	3.1	3.8	4.5										11
7	1.3	2.2	3.2	4.1	5.0	6.0	6.9									11
8	1.6	2.8	4.0	5.3	6.5	7.7	8.9	10.2								6
9	1.9	3.4	5.0	6.6	8.1	9.7	11.2	12.8	14.3							5
10		4.2	6.1	8.0	9.9	11.8	13.8	15.7	17.6							5
11		5.0	7.3	9.6	11.9	14.3	16.6	18.9	21.2	23.5						4
12		5.9	8.6	11.4	14.2	16.9	19.7	22.4	25.2	28.0						7
13		6.8	10.1	13.3	16.5	19.8	23.0	26.3	29.5	32.8	36.0					1
14		7.9	11.6	15.4	19.1	22.9	26.7	30.4	34.2	37.9	41.7					4
15			13.3	17.6	21.9	26.2	30.5	34.9	39.2	43.5	47.8	52.1				4
16			15.1	20.0	24.9	29.8	34.7	39.6	44.5	49.4	54.4	59.3				4
17			17.0	22.5	28.1	33.6	39.1	44.7	50.2	55.8	61.3	66.9	72.4			1
18			19.0	25.2	31.4	37.6	43.8	50.1	56.3	62.5	68.7	74.9	81.1			1
19			21.1	28.0	35.0	41.9	48.8	55.7	62.7	69.6	76.5	83.4	90.4	97.3		2
20				31.0	38.7	46.4	54.0	61.7	69.4	77.1	84.7	92.4	100.1	107.7		3
21				34.2	42.6	51.1	59.5	68.0	76.5	84.9	93.4	101.8	110.3	118.8	127.2	2
22				37.5	46.8	56.0	65.3	74.6	83.9	93.2	102.5	111.7	121.0	130.3	139.6	0
23				40.9	51.1	61.2	71.4	81.5	91.7	101.8	111.9	122.1	132.2	142.4	152.5	3
24				44.5	55.6	66.6	77.7	88.7	99.8	110.8	121.9	132.9	144.0	155.0	166.1	2
25					60.3	72.3	84.3	96.2	108.2	120.2	132.2	144.2	156.2	168.2	180.2	0
26					65.2	78.1	91.1	104.1	117.0	130.0	143.0	155.9	168.9	181.9	194.8	0
27					70.3	84.2	98.2	112.2	126.2	140.2	154.1	168.1	182.1	196.1	210.1	0
28					75.5	90.6	105.6	120.6	135.7	150.7	165.7	180.8	195.8	210.9	225.9	0
29					81.0	97.1	113.3	129.4	145.5	161.6	177.8	193.9	210.0	226.2	242.3	0
30						103.9	121.2	138.4	155.7	173.0	190.2	207.5	224.7	242.0	259.3	0
31						110.9	129.4	147.8	166.2	184.7	203.1	221.5	240.0	258.4	276.8	0
32						118.2	137.8	157.5	177.1	196.7	216.4	236.0	255.7	275.3	294.9	0
33						125.7	146.5	167.4	188.3	209.2	230.1	251.0	271.9	292.8	313.6	0
34						133.4	155.5	177.7	199.9	222.1	244.2	266.4	288.6	310.7	332.9	0
35							164.8	188.3	211.8	235.3	258.8	282.3	305.8	329.3	352.8	0
36							174.3	199.2	224.1	248.9	273.8	298.6	323.5	348.3	373.2	0
37							184.1	210.4	236.7	262.9	289.2	315.4	341.7	367.9	394.2	0
38							194.2	221.9	249.6	277.3	305.0	332.7	360.4	388.1	415.8	0
39							204.5	233.7	262.9	292.1	321.2	350.4	379.6	408.8	437.9	0
40								245.8	276.5	307.2	337.9	368.6	399.3	430.0	460.7	0
41								258.3	290.5	322.8	355.0	387.2	419.5	451.7	484.0	0
42								271.0	304.8	338.7	372.5	406.3	440.2	474.0	507.8	0
43								284.0	319.5	355.0	390.4	425.9	461.4	496.8	532.3	0
44								297.4	334.5	371.7	408.8	445.9	483.1	520.2	557.3	0
45									349.9	388.7	427.6	466.4	505.2	544.1	582.9	0
46									365.6	406.2	446.8	487.4	527.9	568.5	609.1	0
47									381.7	424.0	466.4	508.8	551.1	593.5	635.9	0
48									398.1	442.2	486.4	530.6	574.8	619.0	663.2	0
49									414.8	460.8	506.9	552.9	599.0	645.0	691.1	0
50									431.9	479.8	527.8	575.7	623.7	671.6	719.6	0

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	PART TREE
1	.4															
2	.4	.5														
3	.5	.7	.9													
4	.6	.9	1.3	1.6												
5	.8	1.3	1.8	2.2	2.7											
6	1.0	1.7	2.4	3.1	3.8	4.4										
7	1.3	2.2	3.1	4.1	5.0	5.9	6.9									
8	1.6	2.8	4.0	5.2	6.4	7.6	8.8	10.0								
9	1.9	3.4	4.9	6.5	8.0	9.5	11.1	12.6	14.1							
10		4.1	6.0	7.9	9.8	11.7	13.6	15.5	17.3							
11		4.9	7.2	9.5	11.8	14.0	16.3	18.6	20.9	23.1						
12		5.8	8.5	11.2	13.9	16.6	19.3	22.0	24.7	27.4						
13		6.7	9.9	13.0	16.2	19.4	22.5	25.7	28.8	32.0	35.1					
14		7.7	11.4	15.0	18.7	22.4	26.0	29.7	33.3	36.9	40.6					
15			13.0	17.2	21.4	25.5	29.7	33.9	38.0	42.2	46.3	50.5				
16			14.7	19.4	24.2	28.9	33.6	38.4	43.1	47.8	52.5	57.1				
17			16.5	21.8	27.2	32.5	37.8	43.1	48.4	53.6	58.9	64.1	69.4			
18			18.4	24.4	30.3	36.2	42.2	48.1	53.9	59.8	65.7	71.5	77.3			
19			20.4	27.0	33.6	40.2	46.7	53.3	59.8	66.3	72.7	79.2	85.6	92.		
20				29.8	37.1	44.3	51.5	58.7	65.9	73.	80.1	87.2	94.3	101.3		
21				32.7	40.7	48.6	56.5	64.4	72.2	80.1	87.7	95.5	103.	110.8	118.5	
22				35.7	44.4	53.1	61.7	70.3	78.7	87.	95.6	104.	112.4	120.7	129.	
23				38.8	48.3	57.7	67.0	76.3	85.5	94.	103.8	113.0	121.9	130.9	139.9	
24				42.1	52.3	62.5	72.6	82.6	92.5	102.	112.3	122.	131.8	141.4	151.1	
25					56.5	67.4	78.3	89.0	99.5	110.	120.4	130.9	141.8	152.	162.6	
26					60.8	72.5	84.2	95.7	107.1	118.5	129.8	141.	152.	163.4	174.4	
27					65.3	77.8	90.2	102.5	114.8	126.9	139.0	151.0	162.8	174.7	186.4	
28					69.8	83.2	96.4	109.6	122.6	135.4	148.2	161.1	173.7	186.3	198.8	
29					74.5	88.7	102.8	116.8	130.6	144.3	158.1	171.5	184.9	198.2	211.5	
30						94.4	109.4	124.2	138.9	153.4	167.8	182.1	196.2	210.2	224.5	
31						100.3	116.1	131.8	147.4	162.7	177.9	193.0	208.1	223.1	237.8	
32						106.3	123.0	139.6	155.9	172.1	188.2	204.1	220.	235.8	251.4	
33						112.5	130.1	147.5	164.8	181.9	198.8	215.6	232.2	248.9	265.	
34						118.7	137.3	155.7	173.8	191.8	209.6	227.2	244.8	262.2	279.7	
35							144.7	164.0	183.1	202.0	220.7	239.2	257.7	276.1	294.3	
36							152.3	172.5	192.5	212.4	232.1	251.5	270.8	290.1	309.3	
37							160.0	181.2	202.2	223.0	243.5	263.9	284.3	304.5	324.7	
38							167.9	190.1	212.1	233.8	255.4	276.8	298.1	319.3	340.5	
39							176.0	199.2	222.2	244.9	267.5	289.9	312.2	334.4	356.5	
40								208.5	232.4	256.	279.8	303.4	326.8	350.2	373.4	
41								217.9	242.8	267.5	292.1	316.5	341.0	365.3	389.6	
42								227.6	253.5	279.2	304.8	330.3	355.6	381.0	406.2	
43								237.5	264.5	291.2	318.0	344.6	371.1	397.4	423.6	
44								247.5	275.9	304.1	332.1	360.0	387.8	415.5	443.1	
45									287.4	316.7	345.9	375.0	404.0	432.9	461.7	
46									299.0	329.5	359.9	390.2	420.4	450.4	480.3	
47									310.9	342.7	374.4	406.0	437.5	468.9	500.2	
48									323.0	356.1	389.1	422.0	454.8	487.5		
49									335.3	369.7	404.0	438.1	472.2	506.2		
50									347.9	383.7	419.4	454.9	490.3	525.6		

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNFORKED TREES
DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	SAMPLE TREES
5	.5	.6	.7	.8	.9											3
6	.7	1.1	1.5	1.9	2.3	2.7										12
7	1.0	1.7	2.4	3.1	3.8	4.5	5.2									11
8	1.2	2.3	3.3	4.3	5.4	6.4	7.4	8.5								5
9	1.5	2.9	4.3	5.7	7.1	8.5	9.9	11.2	12.6							4
10		3.6	5.3	7.1	8.9	10.7	12.5	14.2	16.0							5
11		4.3	6.5	8.7	10.9	13.1	15.3	17.5	19.7	21.9						4
12		5.1	7.7	10.4	13.0	15.7	18.4	21.0	23.7	26.3						7
13		5.9	9.1	12.2	15.4	18.5	21.7	24.8	28.0	31.1	34.3					1
14		6.8	10.5	14.2	17.9	21.5	25.2	28.9	32.6	36.2	39.9					4
15			12.0	16.3	20.5	24.8	29.0	33.3	37.5	41.7	46.0	50.2				4
16			13.7	18.5	23.4	28.2	33.1	37.9	42.7	47.6	52.4	57.3				4
17			15.4	20.9	26.4	31.9	37.3	42.8	48.3	53.8	59.3	64.8	70.2			1
18			17.3	23.4	29.6	35.7	41.9	48.1	54.2	60.4	66.5	72.7	78.8			1
19			19.2	26.1	33.0	39.8	46.7	53.6	60.4	67.3	74.2	81.1	87.9	94.8		2
20				28.9	36.5	44.1	51.7	59.4	67.0	74.6	82.2	89.9	97.5	105.1		2
21				31.8	40.2	48.6	57.1	65.5	73.9	82.3	90.7	99.1	107.5	116.0	124.4	2
22				34.9	44.1	53.4	62.6	71.9	81.1	90.3	99.6	108.8	118.1	127.3	136.6	3
23				38.1	48.2	58.3	68.4	78.5	88.7	98.8	108.9	119.0	129.1	139.2	149.3	3
24				41.5	52.5	63.5	74.5	85.5	96.5	107.5	118.6	129.6	140.6	151.6	162.6	2
25					56.9	68.9	80.8	92.8	104.8	116.7	128.7	140.6	152.6	164.5	176.5	0
26					61.6	74.5	87.4	100.4	113.3	126.2	139.2	152.1	165.0	178.0	190.9	2
27					66.4	80.3	94.3	108.2	122.2	136.1	150.1	164.0	178.0	191.9	205.9	0
28					71.4	86.4	101.4	116.4	131.4	146.4	161.4	176.4	191.4	206.4	221.4	0
29					76.5	92.6	108.7	124.8	140.9	157.0	173.1	189.2	205.4	221.5	237.6	0
30						99.1	116.3	133.6	150.8	168.1	185.3	202.5	219.8	237.0	254.2	0
31						105.8	124.2	142.6	161.0	179.4	197.8	216.3	234.7	253.1	271.5	0
32						112.7	132.3	152.0	171.6	191.2	210.8	230.4	250.0	269.7	289.3	0
33						119.9	140.7	161.6	182.5	203.3	224.2	245.1	265.9	286.8	307.6	0
34						127.2	149.4	171.5	193.7	215.8	238.0	260.1	282.3	304.4	326.6	0
35							158.3	181.8	205.2	228.7	252.2	275.6	299.1	322.6	346.1	0
36							167.4	192.3	217.1	241.9	266.8	291.6	316.5	341.3	366.1	0
37							176.9	203.1	229.3	255.6	281.8	308.0	334.3	360.5	386.8	0
38							186.5	214.2	241.9	269.6	297.2	324.9	352.6	380.3	407.9	0
39							196.5	225.6	254.8	283.9	313.1	342.2	371.4	400.5	429.7	0
40								237.3	268.0	298.7	329.3	360.0	390.7	421.3	452.0	0
41								249.3	281.5	313.8	346.0	378.2	410.4	442.7	474.9	0
42								261.6	295.4	329.2	363.1	396.9	430.7	464.5	498.3	0
43								274.2	309.6	345.1	380.5	416.0	451.4	486.9	522.3	0
44								287.1	324.2	361.3	398.4	435.5	472.7	509.8	546.9	0
45									339.1	377.9	416.7	455.6	494.4	533.2	572.0	0
46									354.3	394.9	435.5	476.0	516.6	557.2	597.7	0
47									369.9	412.2	454.6	496.9	539.3	581.6	624.0	0
48									385.8	429.9	474.1	518.3	562.5	606.6	650.8	0
49									402.0	448.0	494.1	540.1	586.1	632.2	678.2	0
50									418.6	466.5	514.4	562.4	610.3	658.2	706.2	0
BASIS TREES	0	0	19	19	14	9	11	6	2	0	0	0	0	0	0	

DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
5	.5	.6	.7	.8	.9											4
6	.7	1.1	1.5	1.9	2.3	2.7										10
7	1.0	1.7	2.4	3.1	3.8	4.5	5.2									12
8	1.2	2.2	3.3	4.3	5.3	6.3	7.4	8.4								4
9	1.5	2.8	4.2	5.6	7.0	8.3	9.7	11.1	12.5							6
10		3.5	5.3	7.0	8.8	10.5	12.3	14.0	15.8							7
11		4.2	6.4	8.5	10.7	12.9	15.0	17.2	19.4	21.5						5
12		5.0	7.6	10.2	12.8	15.4	18.0	20.6	23.2	25.8						4
13		5.8	8.9	12.0	15.0	18.1	21.2	24.3	27.3	30.4	33.4					1
14		6.7	10.3	13.9	17.4	21.0	24.6	28.2	31.7	35.3	38.8					3
15			11.7	15.9	20.0	24.1	28.2	32.3	36.4	40.5	44.6	48.6				2
16			13.3	18.0	22.7	27.4	32.0	36.7	41.3	46.0	50.6	55.2				1
17			15.0	20.3	25.5	30.8	36.1	41.3	46.5	51.7	56.9	62.1	67.3			1
18			16.7	22.6	28.5	34.4	40.3	46.1	52.0	57.8	63.6	69.4	75.3			1
19			18.5	25.1	31.7	38.3	44.7	51.3	57.7	64.1	70.6	77.0	83.4	89.7		3
20				27.7	34.9	42.2	49.3	56.5	63.6	70.7	77.8	84.8	91.9	98.9		3
21				30.4	38.4	46.3	54.1	62.0	69.8	77.6	85.3	93.0	100.7	108.4	116.0	2
22				33.2	41.9	50.5	59.1	67.7	76.2	84.7	93.1	101.5	109.8	118.2	126.4	2
23				36.2	45.6	55.0	64.3	73.6	82.8	92.0	101.1	110.2	119.2	128.2	137.2	3
24				39.2	49.4	59.6	69.6	79.7	89.6	99.5	109.4	119.2	128.9	138.6	148.3	2
25					53.4	64.3	75.2	86.0	96.7	107.3	117.9	128.4	138.9	149.3	159.7	1
26					57.4	69.3	80.9	92.4	103.9	115.3	126.7	137.9	149.1	160.3	171.4	1
27					61.7	74.3	86.7	99.1	111.4	123.5	135.7	147.7	159.6	171.5	183.3	1
28					66.0	79.4	92.7	105.9	119.0	132.0	144.9	157.7	170.4	183.0	195.6	1
29					70.4	84.8	98.9	113.0	126.9	140.7	154.3	167.9	181.4	194.8	208.1	1
30						90.2	105.3	120.2	134.9	149.5	164.0	178.4	192.7	206.9	221.	1
31						95.9	111.8	127.5	143.1	158.6	173.9	189.1	204.2	219.1	234.1	
32						101.6	118.5	135.1	151.6	167.8	184.1	200.1	216.1	231.9	247.6	
33						107.5	125.3	142.9	160.3	177.4	194.5	211.4	228.1	244.8	261.4	
34						113.6	132.3	150.8	169.1	187.2	205.1	222.9	240.5	258.1	275.5	
35							139.5	158.9	178.1	197.1	215.9	234.6	253.	271.5	289.9	
36							146.8	167.2	187.3	207.3	227.0	246.6	266.1	285.4	304.	
37							154.3	175.6	196.8	217.7	238.4	258.9	279.3	299.6	319.8	
38							161.9	184.3	206.4	228.4	250.2	271.5	292.8	314.1	335.	
39							169.7	193.1	216.3	239.3	261.8	284.4	306.7	328.9	351.	
40								202.1	226.3	250.3	273.9	297.4	320.8	344.1	367.2	
41								211.2	236.4	261.5	286.3	311.0	335.4	359.7	383.8	
42								220.4	246.7	272.9	298.9	324.5	350.0	375.4	400.7	
43								230.3	257.7	284.8	311.8	338.5	365.1	391.6	418.1	
44								240.2	268.6	296.9	324.9	352.8	380.6	408.3	435.8	
45									279.7	309.1	338.4	367.6	396.7	425.6	454.	
46									291.1	321.6	352.0	382.3	412.4	442.4	472.2	
47									302.5	334.4	366.2	397.8	429.2	460.5	491.6	
48									314.2	347.4	380.4	413.2	445.9	478.5	510.9	
49									326.2	360.6	394.8	428.9	462.9	496.8	530.6	
50									338.4	374.1	409.6	445.0	480.2	515.2	550.1	
BASIS TREES																

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES-UNFORKED TREES

DOUGLAS-FIR

SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS FACTOR
7	.4	.6	.7	.9	1.0	1.2	1.4									11
8	.8	1.4	1.9	2.5	3.1	3.7	4.3	4.9								6
9	1.1	2.1	3.1	4.2	5.2	6.2	7.2	8.2	9.2							4
10		2.9	4.4	5.8	7.3	8.7	10.2	11.7	13.1							4
11		3.7	5.6	7.6	9.5	11.4	13.3	15.3	17.2	19.1						6
12		4.6	7.0	9.4	11.8	14.2	16.6	19.1	21.5	23.9						7
13		5.5	8.4	11.3	14.3	17.2	20.1	23.1	26.0	28.9	31.9					1
14		6.4	9.9	13.4	16.9	20.4	23.9	27.3	30.8	34.3	37.8					4
15			11.5	15.6	19.6	23.7	27.8	31.8	35.9	40.0	44.0	48.1				4
16			13.2	17.9	22.6	27.3	31.9	36.6	41.3	46.0	50.7	55.4				4
17			15.0	20.3	25.7	31.0	36.3	41.7	47.0	52.3	57.7	63.0	68.3			1
18			16.9	22.9	28.9	34.9	41.0	47.0	53.0	59.0	65.1	71.1	77.1			1
19			18.8	25.6	32.3	39.1	45.8	52.6	59.3	66.1	72.8	79.6	86.3	93.1		2
20				28.4	35.9	43.4	51.0	58.5	66.0	73.5	81.0	88.5	96.0	103.5		3
21				31.4	39.7	48.0	56.3	64.6	72.9	81.2	89.5	97.9	106.2	114.5	122.8	2
22				34.5	43.6	52.8	61.9	71.1	80.2	89.4	98.6	107.6	116.8	125.9	135.1	0
23				37.7	47.8	57.8	67.8	77.8	87.8	97.8	107.9	117.9	127.9	137.9	147.9	3
24				41.1	52.1	63.0	73.9	84.8	95.8	106.7	117.6	128.5	139.5	150.4	161.3	2
25					56.5	68.4	80.3	92.1	104.0	115.9	127.8	139.6	151.5	163.4	175.2	0
26					61.2	74.0	86.9	99.8	112.6	125.5	138.3	151.2	164.0	176.9	189.7	0
27					66.0	79.9	93.8	107.6	121.5	135.4	149.3	163.2	177.0	190.9	204.8	0
28					71.0	86.0	100.9	115.8	130.8	145.7	160.7	175.6	190.5	205.5	220.4	0
29					76.2	92.2	108.3	124.3	140.4	156.4	172.4	188.5	204.5	220.5	236.6	0
30						98.7	115.9	133.1	150.3	167.4	184.6	201.8	219.0	236.1	253.3	0
31						105.5	123.8	142.2	160.5	178.8	197.2	215.5	233.9	252.2	270.6	0
32						112.4	132.0	151.5	171.1	190.6	210.2	229.8	249.3	268.9	288.4	0
33						119.5	140.4	161.2	182.0	202.8	223.6	244.4	265.2	286.0	306.8	0
34						126.9	149.0	171.1	193.2	215.3	237.4	259.5	281.6	303.7	325.8	0
35							157.9	181.4	204.8	228.2	251.6	275.1	298.5	321.9	345.3	0
36							167.1	191.9	216.7	241.5	266.3	291.1	315.8	340.6	365.4	0
37							176.5	202.7	228.9	255.1	281.3	307.5	333.7	359.9	386.1	0
38							186.2	213.9	241.5	269.1	296.8	324.4	352.0	379.7	407.3	0
39							196.2	225.3	254.4	283.5	312.6	341.7	370.8	399.9	429.1	0
40								237.0	267.6	298.2	328.9	359.5	390.1	420.8	451.4	0
41								249.0	281.2	313.4	345.6	377.7	409.9	442.1	474.3	0
42								261.3	295.1	328.9	362.6	396.4	430.2	464.0	497.8	0
43								273.9	309.3	344.7	380.1	415.6	451.0	486.4	521.8	0
44								286.8	323.9	361.0	398.0	435.1	472.2	509.3	546.4	0
45									338.8	377.6	416.4	455.2	493.9	532.7	571.5	0
46									354.0	394.6	435.1	475.6	516.2	556.7	597.2	0
47									369.6	411.9	454.2	496.6	538.9	581.2	623.5	0
48									385.5	429.6	473.8	517.9	562.1	606.2	650.4	0
49									401.7	447.7	493.7	539.7	585.8	631.8	677.8	0
50									418.3	466.2	514.1	562.0	609.9	657.8	705.7	0
BASIS TREES	0	0	12	17	14	9	12	6	2	0	0	0	0	0	0	

NET CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES
DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.4	.6	.7	.9	1.0	1.2	1.3									12
8	.8	1.3	1.9	2.5	3.1	3.7	4.3	4.8								5
9	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1							9
10		2.9	4.3	5.7	7.2	8.6	10.0	11.5	12.9							7
11		3.7	5.6	7.4	9.3	11.2	13.1	15.0	16.9	18.7						8
12		4.5	6.9	9.2	11.6	13.9	16.3	18.7	21.0	23.4						6
13		5.4	8.2	11.1	14.0	16.8	19.7	22.5	25.4	28.2	31.1					2
14		6.3	9.7	13.1	16.5	19.9	23.2	26.6	30.0	33.3	36.7					4
15			11.2	15.2	19.1	23.0	27.0	30.9	34.8	38.7	42.6	46.5				4
16			12.8	17.4	21.9	26.4	30.9	35.4	39.9	44.4	48.8	53.3				
17			14.5	19.7	24.8	29.9	35.0	40.1	45.2	50.3	55.3	60.4	65.4			2
18			16.3	22.1	27.8	33.6	39.3	45.0	50.7	56.4	62.1	67.8	73.4			1
19			18.1	24.6	31.0	37.4	43.8	50.2	56.5	62.9	69.2	75.5	81.7	88.0		3
20				27.2	34.3	41.4	48.5	55.5	62.5	69.5	76.5	83.4	90.4	97.3		3
21				29.9	37.8	45.6	53.3	61.1	68.8	76.4	84.1	91.7	99.3	106.8	114.4	3
22				32.8	41.4	49.9	58.4	66.8	75.2	83.6	91.9	100.2	108.5	116.7	124.9	3
23				35.7	45.1	54.3	63.6	72.8	81.9	91.0	100.0	109.0	118.0	126.9	135.8	3
24				38.8	48.9	59.0	69.0	78.9	88.8	98.6	108.3	118.1	127.7	137.4	146.9	3
25					52.9	63.7	74.5	85.2	95.8	106.4	116.9	127.4	137.8	148.1	158.4	3
26					57.0	68.6	80.2	91.7	103.1	114.4	125.7	136.9	148.0	159.1	170.1	3
27					61.2	73.7	86.1	98.4	110.6	122.7	134.7	146.7	158.6	170.4	182.2	3
28					65.5	78.9	92.1	105.2	118.3	131.2	144.0	156.7	169.4	182.1	194.5	3
29					70.0	84.2	98.3	112.3	126.1	139.9	153.5	167.0	180.5	193.8	207.1	3
30						89.7	104.7	119.5	134.2	148.8	163.2	177.5	191.8	205.9	220.0	3
31						95.3	111.2	126.9	142.5	157.9	173.2	188.3	203.4	218.3	233.2	3
32						101.1	117.9	134.5	150.9	167.2	183.3	199.3	215.2	231.0	246.7	3
33						107.0	124.8	142.3	159.6	176.7	193.7	210.6	227.4	244.1	260.5	3
34						113.1	131.8	150.3	168.4	186.5	204.4	222.1	239.8	257.3	274.7	3
35							138.9	158.3	177.5	196.5	215.3	233.9	252.5	270.9	289.1	3
36							146.3	166.6	186.8	206.7	226.4	246.0	265.4	284.7	304.0	3
37							153.8	175.1	196.2	217.1	237.8	258.3	278.7	299.0	319.1	3
38							161.4	183.8	205.9	227.7	249.4	270.9	292.3	313.5	334.6	3
39							169.2	192.6	215.7	238.6	261.3	283.8	306.1	328.2	350.5	3
40								201.7	225.8	249.7	273.4	296.9	320.3	343.5	366.	3
41								210.9	236.1	261.2	285.8	310.4	334.8	359.1	383.3	3
42								220.3	246.6	272.6	298.4	324.1	349.6	375.	400.	3
43								229.9	257.3	284.4	311.3	338.1	364.7	391.2	417.7	3
44								239.6	268.2	296.5	324.5	352.4	380.	407.9	435.5	3
45									279.3	308.7	338.0	367.2	396.4	425.4	453.4	3
46									290.6	321.3	351.7	382.	412.1	442.2	472.	3
47									302.2	334.0	365.7	397.2	428.6	459.9	491.	3
48									313.9	347.1	380.2	413.2	446.1	478.8	511.	3
49									325.9	360.3	394.5	428.6	462.6	496.6	530.5	3
50									338.1	373.9	409.4	444.8	480.2	515.5	550.8	3
BASIS TREES	0	0	28	23	17	12	14	4	3	2	1	1	1	1	1	

GROSS INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB-UNMARKED TREES
DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	PART TREES
7	.6	.9	1.1	1.3	1.6	1.8	2.0									11
8	2.1	3.6	5.2	6.8	8.3	9.9	11.5	13.0								6
9	3.9	7.4	11.0	14.5	18.0	21.6	25.1	28.7	32.2							5
10		11.8	17.8	23.7	29.7	35.6	41.5	47.5	53.4							5
11		16.8	25.4	34.1	42.7	51.4	60.0	68.7	77.3	86.0						4
12		22.1	33.8	45.4	57.1	68.7	80.4	92.0	103.7	115.3						7
13		27.9	42.8	57.7	72.6	87.5	102.4	117.4	132.3	147.2	162.1					1
14		34.1	52.5	70.9	89.3	107.7	126.2	144.6	163.0	181.4	199.8					4
15			62.8	85.0	107.2	129.3	151.5	173.7	195.9	218.0	240.2	262.4				4
16			73.8	100.0	126.1	152.3	178.5	204.7	230.8	257.0	283.2	309.4				5
17			85.4	115.8	146.3	176.7	207.1	237.5	267.9	298.4	328.8	359.2	389.6			2
18			97.7	132.6	167.5	202.4	237.4	272.3	307.2	342.1	377.0	411.9	446.8			1
19			110.7	150.3	190.0	229.6	269.2	308.9	348.5	388.2	427.8	467.5	507.1	546.8		2
20				168.9	213.5	258.2	302.8	347.4	392.0	436.7	481.3	525.9	570.6	615.2		3
21				188.4	238.3	288.1	338.0	387.8	437.7	487.6	537.4	587.3	637.1	687.0	736.8	2
22				208.8	264.2	319.5	374.8	430.2	485.5	540.8	596.2	651.5	706.8	762.2	817.5	0
23				230.2	291.2	352.3	413.3	474.4	535.5	596.5	657.6	718.7	779.7	840.8	901.8	3
24				252.4	319.5	386.5	453.5	520.6	587.6	654.6	721.7	788.7	855.7	922.8	989.8	2
25					348.9	422.1	495.4	568.6	641.9	715.2	788.4	861.7	934.9	1008.2	1081.5	0
26					379.5	459.2	538.9	618.7	698.4	778.1	857.9	937.6	1017.3	1097.1	1176.8	0
27					411.2	497.7	584.1	670.6	757.0	843.5	930.0	1016.4	1102.9	1189.3	1275.8	0
28					444.2	537.6	631.0	724.4	817.9	911.3	1004.7	1098.2	1191.6	1285.0	1378.5	0
29					478.3	578.9	679.6	780.2	880.9	981.6	1082.2	1182.9	1283.5	1384.2	1484.8	0
30						621.7	729.8	838.0	946.1	1054.2	1162.4	1270.5	1378.6	1486.8	1594.9	0
31						665.9	781.8	897.6	1013.5	1129.4	1245.2	1361.1	1476.9	1592.8	1708.6	0
32						711.6	835.4	959.2	1083.1	1206.9	1330.8	1454.6	1578.4	1702.3	1826.1	0
33						758.7	890.7	1022.8	1154.9	1286.9	1419.0	1551.0	1683.1	1815.2	1947.2	0
34						807.2	947.7	1088.3	1228.8	1369.4	1509.9	1650.5	1791.0	1931.5	2072.1	0
35							1006.4	1155.7	1305.0	1454.3	1603.5	1752.8	1902.1	2051.4	2200.6	0
36							1066.8	1225.1	1383.3	1541.6	1699.9	1858.1	2016.4	2174.7	2332.9	0
37							1128.9	1296.4	1463.9	1631.4	1798.9	1966.4	2133.9	2301.4	2468.9	0
38							1192.7	1369.7	1546.6	1723.6	1900.6	2077.6	2254.6	2431.6	2608.6	0
39							1258.1	1444.9	1631.6	1818.3	2005.0	2191.8	2378.5	2565.2	2752.0	0
40								1522.0	1718.7	1915.5	2112.2	2308.9	2505.6	2702.3	2899.1	0
41								1601.1	1808.1	2015.1	2222.0	2429.0	2635.9	2842.9	3049.9	0
42								1682.2	1899.6	2117.1	2334.6	2552.0	2769.5	2986.9	3204.4	0
43								1765.2	1993.4	2221.6	2449.8	2678.0	2906.2	3134.4	3362.6	0
44								1850.1	2089.3	2328.5	2567.8	2807.0	3046.2	3285.4	3524.6	0
45									2187.5	2437.9	2688.4	2938.9	3189.3	3439.8	3690.3	0
46									2287.8	2549.8	2811.8	3073.8	3335.7	3597.7	3859.7	0
47									2390.4	2664.1	2937.9	3211.6	3485.3	3759.1	4032.8	0
48									2495.1	2780.9	3066.6	3352.4	3638.1	3923.9	4209.6	0
49									2602.1	2900.1	3198.1	3496.1	3794.1	4092.2	4390.2	0
50									2711.3	3021.8	3332.3	3642.8	3953.4	4263.9	4574.4	0
BASIS																

NET INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB
DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.5	.8	1.0	1.3	1.5	1.8	2.0									12
8	1.8	3.2	4.8	6.3	7.9	9.5	11.2	12.8								4
9	3.3	6.5	9.8	13.3	16.9	20.5	24.1	27.8	31.4							9
10		10.1	15.6	21.3	27.1	33.1	39.1	45.2	51.4							7
11		14.1	21.8	29.8	38.1	46.6	55.4	64.2	73.2	82.2						2
12		18.2	28.2	38.6	49.4	60.6	72.2	84.1	96.2	108.4						1
13		22.5	34.8	47.5	60.8	74.8	89.3	104.4	119.9	135.7	151.7					1
14		26.8	41.2	56.2	72.0	88.8	106.6	125.1	144.2	164.0	183.9					1
15			47.6	64.7	83.0	102.7	123.8	146.1	169.3	193.1	217.3	241.5				4
16			53.7	72.8	93.5	116.3	141.1	167.5	195.0	223.2	251.8	280.6				5
17			59.5	80.4	103.7	129.9	158.6	189.2	221.2	254.1	287.4	321.0	354.6			1
18			64.9	87.7	113.7	143.4	176.3	211.4	248.1	285.8	324.1	362.6	401.3			1
19			69.9	94.5	123.6	157.2	194.4	234.2	275.7	318.4	361.7	405.5	449.4	493.4		3
20				101.2	133.5	171.2	212.9	257.5	303.9	351.7	400.3	449.4	498.8	548.2		3
21				107.7	143.6	185.5	231.9	281.3	332.8	385.7	439.7	494.3	549.4	604.6	660.0	2
22				114.2	153.9	200.3	251.3	305.5	362.2	420.4	479.9	540.3	601.1	662.4	723.8	2
23				120.9	164.6	215.4	271.1	330.3	392.1	455.8	521.0	587.1	654.0	721.4	789.1	2
24				127.8	175.7	230.9	291.3	355.5	422.6	491.8	562.7	634.9	708.0	781.7	855.8	2
25					187.1	246.8	311.9	381.1	453.5	528.4	605.2	683.5	763.0	843.2	924.0	1
26					198.8	263.0	332.8	407.1	484.9	565.6	648.4	733.2	818.9	905.8	993.5	2
27					210.9	279.5	354.1	433.5	516.8	603.3	692.3	783.3	875.8	969.6	1064.3	0
28					223.2	296.2	375.7	460.3	549.2	641.6	736.8	834.3	933.7	1034.4	1136.3	2
29					235.8	313.3	397.6	487.4	582.0	680.4	782.0	886.1	993.4	1103.3	1215.5	1
30						330.6	419.8	515.0	615.2	719.7	827.8	938.7	1053.0	1167.6	1283.8	2
31						348.1	442.2	542.8	648.9	759.6	874.2	992.6	1112.4	1235.0	1359.3	2
32						366.0	465.0	571.0	683.0	800.0	921.2	1045.9	1173.7	1303.8	1435.9	2
33						384.0	488.1	599.6	717.5	840.8	968.8	1100.6	1235.7	1373.5	1513.6	2
34						402.3	511.4	628.5	752.4	882.2	1016.9	1155.9	1298.5	1444.1	1592.2	1
35							535.1	657.8	787.8	924.0	1065.7	1211.9	1362.1	1515.6	1671.9	2
36							559.0	687.4	823.5	966.3	1114.4	1268.6	1426.5	1588.0	1753.6	1
37							583.3	717.3	859.6	1009.1	1164.8	1325.8	1491.5	1661.2	1834.1	1
38							607.8	747.6	896.2	1052.4	1215.2	1383.8	1557.3	1735.2	1916.8	2
39							632.6	778.2	933.1	1096.1	1266.1	1442.3	1623.8	1810.0	2000.2	1
40								809.2	970.5	1140.3	1317.5	1501.4	1691.0	1885.4	2084.6	1
41								840.5	1008.2	1184.9	1368.5	1561.0	1758.9	1961.2	2169.8	1
42								872.2	1046.2	1230.0	1422.0	1621.5	1827.5	2039.0	2256.1	1
43								904.1	1084.9	1275.5	1475.2	1682.4	1896.7	2117.1	2343.9	1
44								936.4	1124.7	1321.5	1528.6	1743.8	1966.4	2195.8	2431.8	1
45									1163.8	1367.9	1582.6	1806.2	2037.2	2275.2	2519.4	1
46									1202.7	1414.8	1637.1	1868.7	2108.4	2355.4	2608.4	1
47									1242.7	1460.1	1690.2	1931.9	2180.2	2436.1	2699.1	1
48									1283.2	1509.8	1747.7	1996.7	2253.2	2517.8	2789.2	1
49									1324.3	1558.0	1803.7	2060.3	2325.8	2600.1	2882.1	1
50									1365.1	1606.6	1860.2	2124.9	2399.5	2683.1	2976.6	1
BASIS TREES	2	3	13	20	17	12	14	6	3	2	1	1	1	1	1	

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNFORKED TREES
DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.3	.4	.5	.6	.7	.8	1.0									0
8	1.2	2.1	2.9	3.8	4.7	5.6	6.5	7.4								3
9	2.4	4.7	6.9	9.1	11.4	13.6	15.8	18.1	20.3							4
10		8.0	12.0	16.0	20.0	24.0	28.0	32.1	36.1							5
11		11.9	18.0	24.2	30.3	36.4	42.6	48.7	54.8	61.0						4
12		16.3	24.8	33.4	41.9	50.5	59.1	67.6	76.2	84.8						7
13		21.1	32.3	43.6	54.8	66.1	77.3	88.6	99.8	111.1	122.4					1
14		26.3	40.5	54.7	68.8	83.0	97.2	111.4	125.6	139.8	154.0					4
15			49.2	66.6	84.0	101.3	118.7	136.1	153.5	170.8	188.2	205.6				4
16			58.6	79.4	100.2	121.0	141.7	162.5	183.3	204.1	224.9	245.7				4
17			68.6	93.0	117.4	141.8	166.3	190.7	215.1	239.5	263.9	288.4	312.8			1
18			79.2	107.4	135.7	164.0	192.3	220.6	248.8	277.1	305.4	333.7	362.0			1
19			90.3	122.7	155.1	187.4	219.8	252.1	284.5	316.9	349.2	381.6	413.9	446.3		2
20				138.8	175.4	212.1	248.7	285.4	322.1	358.7	395.4	432.1	468.7	505.4		2
21				155.6	196.8	238.0	279.2	320.4	361.6	402.7	443.9	485.1	526.3	567.5	608.7	2
22				173.3	219.2	265.2	311.1	357.0	403.0	448.9	494.8	540.7	586.7	632.6	678.5	0
23				191.8	242.7	293.6	344.5	395.4	446.3	497.2	548.0	598.9	649.8	700.7	751.6	3
24				211.1	267.2	323.3	379.3	435.4	491.5	547.6	603.6	659.7	715.8	771.8	827.9	2
25					292.7	354.2	415.7	477.1	538.6	600.1	661.5	723.0	784.5	846.0	907.4	0
26					319.3	386.4	453.5	520.5	587.6	654.7	721.8	788.9	856.0	923.1	990.2	0
27					346.9	419.8	492.7	565.7	638.6	711.5	784.4	857.4	930.3	1003.2	1076.1	0
28					375.5	454.5	533.5	612.4	691.4	770.4	849.4	928.4	1007.4	1086.4	1165.3	0
29					405.1	490.4	575.7	660.9	746.2	831.5	916.7	1002.0	1087.2	1172.5	1257.8	0
30						527.6	619.3	711.1	802.9	894.6	986.4	1078.1	1169.9	1261.7	1353.4	0
31						566.0	664.5	763.0	861.4	959.9	1058.4	1156.9	1255.3	1353.8	1452.3	0
32						605.7	711.1	816.5	921.9	1027.4	1132.8	1238.2	1343.6	1449.0	1554.4	0
33						646.7	759.2	871.8	984.4	1096.9	1209.5	1322.0	1434.6	1547.2	1659.7	0
34						688.9	808.8	928.7	1048.7	1168.6	1288.6	1408.5	1528.4	1648.4	1768.3	0
35							859.8	987.4	1114.9	1242.4	1370.0	1497.5	1625.0	1752.6	1880.1	0
36							912.4	1047.7	1183.1	1318.4	1453.8	1589.1	1724.5	1859.8	1995.1	0
37							966.4	1109.7	1253.1	1396.5	1539.9	1683.3	1826.6	1970.0	2113.4	0
38							1021.8	1173.5	1325.1	1476.7	1628.4	1780.0	1931.6	2083.3	2234.9	0
39							1078.8	1238.9	1399.0	1559.1	1719.2	1879.3	2039.4	2199.5	2359.6	0
40								1306.0	1474.8	1643.6	1812.4	1981.2	2150.0	2318.8	2487.6	0
41								1374.8	1552.5	1730.2	1908.0	2085.7	2263.4	2441.1	2618.8	0
42								1445.3	1632.2	1819.0	2005.9	2192.7	2379.6	2566.4	2753.2	0
43								1517.5	1713.7	1909.9	2106.1	2302.3	2498.5	2694.7	2890.9	0
44								1591.5	1797.2	2003.0	2208.8	2414.5	2620.3	2826.1	3031.8	0
45									1883.6	2098.2	2313.7	2529.3	2744.9	2960.4	3176.0	0
46									1969.9	2195.5	2421.1	2646.6	2872.2	3097.8	3323.4	0
47									2059.2	2295.0	2530.8	2766.6	3002.4	3238.2	3474.0	0
48									2150.3	2396.6	2642.8	2889.1	3135.3	3381.6	3627.8	0
49									2243.4	2500.3	2757.2	3014.2	3271.1	3528.0	3784.9	0
50									2338.4	2606.2	2874.0	3141.8	3409.6	3677.4	3945.3	0
BASIS TREES	0	0	1	7	12	8	12	6	2	0	0	0	0	0	0	

DOUGLAS-FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.2	.4	.5	.6	.7	.8	.9									12
8	.9	1.8	2.6	3.5	4.5	5.4	6.3	7.2								4
9	1.9	3.9	6.0	8.3	10.5	12.9	15.2	17.5	19.8							6
10		6.5	10.2	14.1	18.1	22.2	26.4	30.6	34.8							7
11		9.3	14.7	20.5	26.5	32.7	39.1	45.5	52.0	58.5						4
12		12.4	19.5	27.2	35.3	43.8	52.5	61.6	70.7	79.9						3
13		15.5	24.4	33.9	44.1	54.9	66.3	78.2	90.3	102.6	114.9					1
14		18.5	29.0	40.3	52.5	65.9	80.1	95.1	110.5	126.2	142.0					4
15			33.4	46.2	60.5	76.3	93.6	112.0	131.1	150.6	170.2	189.8				4
16			37.2	51.4	67.7	86.3	106.9	128.0	150.0	175.4	199.2	223.0				5
17			40.5	55.9	74.2	95.7	119.9	146.0	173.2	201.0	229.1	257.1	285.1			1
18			43.2	59.5	80.0	104.7	132.7	163.0	194.6	226.9	259.5	292.2	324.8			1
19			45.0	62.4	85.3	113.4	145.4	180.0	216.1	253.1	290.5	328.1	365.5	402.7		3
20				64.7	90.2	121.9	158.0	197.0	237.7	279.5	321.8	364.4	406.9	449.4		4
21				66.4	94.8	130.2	170.5	213.9	259.4	306.1	353.5	401.0	448.1	496.8	544.4	3
22				67.8	98.2	138.9	180.9	230.8	281.0	332.7	385.3	438.5	491.8	545.2	598.4	3
23				68.9	103.6	146.6	195.2	247.6	302.6	359.4	417.3	475.1	535.1	594.7	653.2	3
24				69.9	107.8	154.6	207.3	264.3	324.1	386.0	449.4	513.7	578.6	643.7	708.9	3
25					113.0	162.5	219.3	280.6	345.4	410.5	481.5	551.6	622.5	693.8	765.2	
26					116.2	170.2	231.3	296.8	366.5	438.9	513.5	589.5	666.4	744.2	822.2	
27					120.2	177.7	242.5	312.8	387.4	465.2	545.5	627.3	711.8	795.	879.6	
28					124.0	185.0	253.7	328.5	408.2	491.2	577.3	665.5	755.3	846.	937.4	
29					127.7	192.0	264.6	343.9	428.4	517.1	607.0	700.4	799.1	897.1	995.4	
30						198.8	275.3	359.0	448.5	542.7	638.3	741.1	844.1	948.4	1053.9	
31						205.3	285.5	373.8	468.3	568.1	671.8	778.8	888.4	999.8	1111.5	
32						211.5	295.6	388.3	487.8	593.1	702.9	816.2	932.6	1051.1	1171.0	
33						217.5	305.4	402.4	507.0	617.8	733.7	854.6	976.8	1102.5	1229.0	
34						223.1	314.8	416.1	525.8	642.2	764.1	893.0	1021.1	1153.1	1288.9	
35							323.9	429.7	544.4	666.2	794.4	931.4	1065.4	1204.8	1347.7	
36							332.6	442.9	562.5	691.1	824.3	968.3	1108.1	1253.8	1406.5	
37							341.1	455.7	580.3	715.2	853.7	1003.1	1151.4	1306.6	1468.1	
38							349.3	468.1	597.8	738.5	883.0	1038.1	1194.6	1357.7	1529.6	
39							357.0	480.2	614.8	759.2	911.2	1073.1	1237.1	1408.4	1588.6	
40								491.9	631.5	781.5	940.4	1108.7	1279.5	1458.9	1648.1	
41								503.3	647.8	803.4	968.4	1141.6	1321.6	1508.7	1698.	
42								514.3	663.7	824.1	996.1	1174.1	1363.2	1558.8	1758.6	
43								524.9	679.3	844.6	1023.6	1206.4	1404.6	1605.9	1811.9	
44								535.2	694.4	866.5	1050.7	1238.4	1446.5	1654.6	1869.	
45									709.1	886.9	1076.6	1270.2	1486.	1703.9	926.5	
46									723.4	906.7	1102.2	1302.5	1526.	1755.9	98 .8	
47									737.3	926.1	1128.1	1334.8	1565.7	1798.4	8.	
48									750.8	945.2	1153.7	1367.1	1604.1	1840.5	9 .	
49									763.9	963.6	1177.9	1398.2	1640.5	1880.1	19.	
50									776.6	981.5	1202.2	1426.1	1673.9	1918.8	.9	
BASIS TREES			13		17	12	14									

TOTAL STEM GROSS CUBIC FOOT VOLUME-UNFORKED TREES
ASPEN
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
1	.1															5
2	.1	.2														5
3	.2	.4	.7													5
4	.4	.8	1.1	1.5												5
5	.6	1.2	1.8	2.3	2.9											11
6	.9	1.7	2.5	3.4	4.2	5.0										20
7	1.2	2.3	3.4	4.6	5.7	6.8	8.0									20
8	1.5	3.0	4.5	5.9	7.4	8.9	10.4	11.9								12
9	1.9	3.8	5.6	7.5	9.4	11.3	13.1	15.0	16.9							11
10		4.7	7.0	9.3	11.6	13.9	16.2	18.5	20.8							7
11		5.6	8.4	11.2	14.0	16.8	19.6	22.4	25.2	28.0						9
12		6.7	10.0	13.3	16.7	20.0	23.3	26.7	30.0	33.3						6
13		7.8	11.8	15.7	19.6	23.5	27.4	31.3	35.2	39.1	43.0					5
14		9.1	13.6	18.2	22.7	27.2	31.7	36.3	40.8	45.3	49.9					5
15			15.6	20.8	26.0	31.2	36.4	41.6	46.8	52.0	57.2	62.4				1
16			17.8	23.7	29.6	35.5	41.5	47.4	53.3	59.2	65.1	71.0				0
17			20.1	26.8	33.4	40.1	46.8	53.5	60.1	66.8	73.5	80.2	86.9			1
18			22.5	30.0	37.5	45.0	52.5	59.9	67.4	74.9	82.4	89.9	97.4			0
19			25.1	33.4	41.8	50.1	58.4	66.8	75.1	83.5	91.8	100.2	108.5	116.8		1
20				37.0	46.3	55.5	64.7	74.0	83.2	92.5	101.7	111.0	120.2	129.5		0
21				40.8	51.0	61.2	71.4	81.6	91.8	102.0	112.2	122.3	132.5	142.7	152.9	0
22				44.8	56.0	67.2	78.3	89.5	100.7	111.9	123.1	134.3	145.5	156.6	167.8	0
23				48.9	61.2	73.4	85.6	97.8	110.1	122.3	134.5	146.7	159.0	171.2	183.4	0
24				53.3	66.6	79.9	93.2	106.5	119.8	133.2	146.5	159.8	173.1	186.4	199.7	0
25					72.3	86.7	101.1	115.6	130.0	144.5	158.9	173.4	187.8	202.3	216.7	0
26					78.2	93.8	109.4	125.0	140.6	156.3	171.9	187.5	203.1	218.8	234.4	0
27					84.3	101.1	118.0	134.8	151.7	168.5	185.4	202.2	219.1	235.9	252.8	0
28					90.6	108.8	126.9	145.0	163.1	181.2	199.4	217.5	235.6	253.7	271.8	0
29					97.2	116.7	136.1	155.5	175.0	194.4	213.8	233.3	252.7	272.2	291.6	0
30						124.8	145.6	166.4	187.2	208.0	228.8	249.6	270.4	291.2	312.0	0
31						133.3	155.5	177.7	199.9	222.1	244.4	266.6	288.8	311.0	333.2	0
32						142.0	165.7	189.4	213.0	236.7	260.4	284.0	307.7	331.4	355.0	0
33						151.0	176.2	201.4	226.6	251.7	276.9	302.1	327.2	352.4	377.6	0
34						160.3	187.1	213.8	240.5	267.2	293.9	320.6	347.4	374.1	400.8	0
35							198.2	226.5	254.8	283.2	311.5	339.8	368.1	396.4	424.7	0
36							209.7	239.7	269.6	299.6	329.5	359.5	389.4	419.4	449.3	0
37							221.5	253.2	284.8	316.4	348.1	379.7	411.4	443.0	474.6	0
38							233.7	267.0	300.4	333.8	367.1	400.5	433.9	467.3	500.6	0
39							246.1	281.3	316.4	351.6	386.7	421.9	457.0	492.2	527.3	0
40								295.9	332.9	369.8	406.8	443.8	480.8	517.7	554.7	0
41								310.8	349.7	388.6	427.4	466.3	505.1	544.0	582.8	0
42								326.2	367.0	407.7	448.5	489.3	530.0	570.8	611.6	0
43								341.9	384.6	427.4	470.1	512.8	555.6	598.3	641.1	0
44								358.0	402.7	447.5	492.2	537.0	581.7	626.5	671.2	0
45									421.3	468.1	514.9	561.7	608.5	655.3	702.1	0
46									440.2	489.1	538.0	586.9	635.8	684.7	733.6	0
47									459.5	510.6	561.6	612.7	663.8	714.8	765.9	0
48									479.3	532.5	585.8	639.0	692.3	745.5	798.8	0
49									499.5	555.0	610.5	665.9	721.4	776.9	832.4	0
50									520.1	577.8	635.6	693.4	751.2	809.0	866.7	0

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.0															0
2	.1	.2														0
3	.2	.4	.6													0
4	.3	.6	1.0	1.5												0
5	.5	.9	1.4	2.0	2.7											13
6	.6	1.2	2.0	2.8	3.7	4.7										26
7	.7	1.6	2.5	3.6	4.8	6.2	7.8									24
8	.9	1.9	3.0	4.3	5.9	7.7	9.7	11.9								16
9	1.0	2.1	3.4	5.0	6.9	9.1	11.6	14.7	16.9							17
10		2.3	3.8	5.6	7.7	10.3	13.4	17.0	20.8							12
11		2.5	4.1	6.0	8.4	11.3	14.8	19.1	24.2	28.0						15
12		2.6	4.3	6.3	8.9	12.0	15.9	20.7	26.5	33.3						10
13		2.6	4.4	6.5	9.2	12.5	16.6	21.8	28.2	36.3	43.0					7
14		2.6	4.4	6.6	9.3	12.7	17.0	22.4	29.2	37.9	48.8					4
15			4.4	6.5	9.3	12.7	17.0	22.6	29.6	38.7	50.2	62.4				5
16			4.3	6.5	9.1	12.5	16.8	22.3	29.4	38.6	50.5	65.9				5
17			4.3	6.4	8.9	12.2	16.3	21.7	28.7	37.8	49.7	65.4	85.9			1
18			4.3	6.2	8.7	11.8	15.7	20.9	27.6	36.4	48.1	63.5	84.1			3
19			4.3	6.0	8.5	11.4	15.1	19.9	26.3	34.6	45.8	60.7	80.7	107.6		1
20				5.8	8.4	11.1	14.5	19.0	24.8	32.6	43.0	57.1	76.3	102.1		1
21				5.7	8.3	10.9	14.1	18.2	23.5	30.6	40.1	53.1	70.9	95.0	128.7	1
22				5.5	8.4	10.8	13.7	17.5	22.3	28.7	37.3	49.1	65.3	87.6	118.7	3
23				5.5	8.5	10.8	13.6	17.3	21.3	27.3	34.7	45.1	59.6	79.8	108.1	3
24				5.8	8.8	11.0	13.6	16.7	20.6	25.7	32.4	41.6	54.3	72.2	97.4	3
25					9.1	11.3	13.8	16.7	20.2	24.7	30.6	38.6	49.7	65.7	87.7	1
26					9.6	11.8	14.2	16.9	20.3	24.3	29.4	36.3	45.7	59.	77.9	3
27					10.1	12.3	14.7	17.4	20.4	24.0	28.6	34.6	43.6	53.9	69.8	3
28					10.7	13.0	15.4	18.0	20.9	24.2	28.3	33.5	40.4	49.8	63.2	1
29					11.4	13.7	16.2	18.8	21.6	24.8	28.5	33.1	39.6	46.9	58.	1
30						14.6	17.1	19.7	22.5	25.6	29.1	33.2	38.2	45.1	54.2	
31						15.4	18.1	20.8	23.7	26.7	30.3	33.8	38.4	44.1	51.8	
32						16.4	19.2	22.0	24.9	28.0	31.2	34.8	39.1	44.0	51.5	
33						17.4	20.3	23.3	26.3	29.4	32.7	36.1	40.6	44.6	51.2	
34						18.4	21.5	24.6	27.8	31.0	34.3	37.8	41.5	45.7	51.7	
35							22.8	26.0	29.3	32.7	36.1	39.6	43.1	47.3	51.9	
36							24.1	27.5	31.0	34.5	38.0	41.6	45.4	49.3	53.6	
37							25.4	29.0	32.7	36.3	40.0	43.8	47.6	51.6	55.8	
38							26.8	30.6	34.4	38.3	42.1	46.0	50.	54.1	58.	
39							28.2	32.2	36.3	40.3	44.4	48.4	52.5	56.7	61.	
40								33.9	38.1	42.4	46.6	50.9	55.	59.5	64.2	
41								35.6	40.1	44.5	49.0	53.4	57.9	62.5	67.4	
42								37.4	42.2	46.7	51.4	56.1	60.7	65.6	70.8	
43								39.3	44.3	48.9	53.8	58.7	63.6	68.6	74.0	
44								41.0	46.1	51.2	56.4	61.5	66.6	71.8	76.9	
45									48.2	53.6	59.0	64.3	69.7	75.	80.4	
46									50.4	56.1	61.6	67.2	72.8	78.4	84.	
47									52.6	58.5	64.3	70.	76.	81.9	87.8	
48									54.9	61.	67.1	73.2	79.3	85.4	91.5	
49									57.2	63.5	69.9	76.3	82.6	89.	95.	
50									59.5	66.2	72.8	79.4	86.	92.6	99.2	
BASIC TREES																

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNBARKED TREES
ASPEN
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASI TR
5	.4	.6	.9	1.1	1.3											11
6	.6	1.2	1.8	2.4	2.9	3.5										20
7	.9	1.8	2.8	3.7	4.6	5.6	6.5									20
8	1.2	2.5	3.8	5.1	6.5	7.8	9.1	10.4								12
9	1.5	3.2	5.0	6.7	8.4	10.2	11.9	13.7	15.4							11
10		4.0	6.2	8.4	10.6	12.8	15.0	17.2	19.4							7
11		4.9	7.6	10.3	13.0	15.7	18.4	21.1	23.8	26.5						5
12		5.9	9.1	12.3	15.6	18.8	22.1	25.3	28.5	31.8						
13		6.9	10.7	14.5	18.4	22.2	26.0	29.9	33.7	37.5	41.3					6
14		8.0	12.5	16.9	21.4	25.8	30.3	34.8	39.2	43.7	48.1					3
15			14.3	19.4	24.6	29.7	34.9	40.0	45.1	50.3	55.4	60.5				1
16			16.3	22.1	28.0	33.9	39.7	45.6	51.4	57.3	63.2	69.0				1
17			18.4	25.0	31.6	38.3	44.9	51.5	58.2	64.8	71.4	78.0	84.7			1
18			20.6	28.1	35.5	42.9	50.4	57.8	65.3	72.7	80.1	87.6	95.0			3
19			23.0	31.3	39.6	47.9	56.2	64.5	72.8	81.1	89.4	97.7	106.0	114.3		1
20				34.7	43.9	53.1	62.3	71.5	80.7	89.9	99.1	108.3	117.5	126.7		1
21				38.2	48.4	58.5	68.7	78.8	89.0	99.1	109.3	119.4	129.6	139.7	149.9	1
22				41.9	53.1	64.2	75.4	86.5	97.7	108.8	120.0	131.1	142.3	153.4	164.6	3
23				45.8	58.0	70.2	82.4	94.6	106.8	119.0	131.2	143.4	155.6	167.8	179.9	3
24				49.9	63.2	76.5	89.7	103.0	116.3	129.6	142.9	156.1	169.4	182.7	196.0	1
25					68.5	83.0	97.4	111.8	126.2	140.6	155.0	169.5	183.9	198.3	212.7	3
26					74.1	89.7	105.3	120.9	136.5	152.1	167.7	183.3	198.9	214.5	230.1	3
27					79.9	96.8	113.6	130.4	147.2	164.1	180.9	197.7	214.5	231.4	248.2	3
28					86.0	104.1	122.2	140.3	158.4	176.5	194.5	212.6	230.7	248.8	266.9	3
29					92.2	111.6	131.1	150.5	169.9	189.3	208.7	228.1	247.5	266.9	286.4	3
30						119.5	140.2	161.0	181.8	202.6	223.4	244.1	264.9	285.7	306.5	3
31						127.6	149.8	171.9	194.1	216.3	238.5	260.7	282.9	305.1	327.3	3
32						135.9	159.6	183.2	206.9	230.5	254.2	277.8	301.4	325.1	348.7	3
33						144.5	169.7	194.8	220.0	245.1	270.3	295.4	320.6	345.7	370.9	3
34						153.4	180.1	206.8	233.5	260.2	286.9	313.6	340.3	367.0	393.7	3
35							190.9	219.2	247.5	275.8	304.1	332.4	360.7	388.9	417.2	3
36							201.9	231.9	261.8	291.8	321.7	351.6	381.6	411.5	441.4	3
37							213.3	244.9	276.6	308.2	339.8	371.4	403.1	434.7	466.3	3
38							225.0	258.4	291.7	325.1	358.4	391.8	425.1	458.5	491.9	3
39							237.0	272.1	307.3	342.4	377.5	412.7	447.8	483.0	518.1	3
40								286.3	323.2	360.2	397.2	434.1	471.1	508.1	545.0	3
41								300.7	339.6	378.4	417.3	456.1	494.9	533.8	572.6	3
42								315.6	356.4	397.1	437.9	478.6	519.4	560.1	600.9	3
43								330.8	373.5	416.2	459.0	501.7	544.4	587.1	629.8	3
44								346.4	391.1	435.8	480.6	525.3	570.0	614.8	659.5	3
45									409.1	455.9	502.6	549.4	596.2	643.0	689.8	3
46									427.4	476.3	525.2	574.1	623.0	671.9	720.8	3
47									446.2	497.3	548.3	599.4	650.4	701.4	752.5	3
48									465.4	518.7	571.9	625.1	678.4	731.6	784.9	3
49									485.0	540.5	596.0	651.5	706.9	762.4	817.9	3
50									505.0	562.8	620.5	678.3	736.1	793.9	851.6	3

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.3	.4	.7	.9	1.1											12
6	.4	.8	1.3	1.8	2.4	3.1										24
7	.5	1.2	1.9	2.7	3.7	4.7	6.0									24
8	.6	1.5	2.4	3.5	4.8	6.3	8.1	10.1								17
9	.7	1.7	2.9	4.2	5.8	7.8	10.1	12.8	15.4							19
10		1.9	3.2	4.8	6.7	9.1	11.8	15.2	19.3							14
11		2.0	3.5	5.3	7.5	10.1	13.4	17.3	22.2	26.5						1
12		2.1	3.7	5.6	8.0	10.9	14.5	19.1	24.7	31.7						2
13		2.2	3.8	5.8	8.3	11.4	15.4	20.3	26.6	34.4	41.3					2
14		2.2	3.9	5.9	8.5	11.7	15.9	21.1	27.8	36.4	47.3					4
15			3.9	5.9	8.5	11.8	16.0	21.4	28.4	37.5	49.2	60.5				2
16			3.9	5.9	8.5	11.7	15.9	21.3	28.4	37.7	49.9	61.8				1
17			3.9	5.9	8.3	11.5	15.6	20.9	27.9	37.2	49.5	61.8	84.7			1
18			3.9	5.8	8.2	11.2	15.1	20.2	27.0	36.1	48.2	59.9	86.4			2
19			3.9	5.8	8.1	10.9	14.6	19.5	25.9	34.5	46.2	57.3	83.6	113.2		1
20				5.8	8.0	10.7	14.1	18.6	24.6	32.7	43.7	54.2	79.5	108.1		2
21				5.9	8.0	10.6	13.8	17.9	23.4	30.8	40.9	50.9	74.4	101.6	129.5	1
22				6.0	8.1	10.5	13.5	17.3	22.3	29.0	38.2	47.8	68.8	94.0	129.7	1
23				6.3	8.3	10.6	13.4	16.9	21.4	27.4	35.6	44.7	63.2	86.1	118.7	
24				6.5	8.5	10.8	13.4	16.7	20.7	26.1	33.3	41.4	57.7	78.1	107.4	
25					8.9	11.1	13.7	16.7	20.4	25.1	31.5	39.2	53.7	72.5	96.4	2
26					9.4	11.6	14.1	16.9	20.3	24.6	30.9	37.8	48.5	63.8	86.1	1
27					9.9	12.2	14.6	17.4	20.5	24.4	29.3	35.9	45.5	58.1	77.1	
28					10.5	12.8	15.3	18.0	21.0	24.6	29.0	34.7	43.5	55.4	69.4	
29					11.1	13.6	16.1	18.8	21.8	25.1	29.1	34.1	42.7	49.9	64.1	
30						14.4	17.0	19.8	22.7	25.9	29.6	34.1	39.8	47.6	58.6	1
31						15.3	18.0	20.8	23.8	27.0	30.5	34.6	39.6	46.5	55.2	1
32						16.2	19.1	22.0	25.0	28.2	31.6	35.5	40.2	45.8	53.4	
33						17.2	20.2	23.3	26.4	29.7	33.1	36.8	41.3	46.1	52.5	
34						18.2	21.4	24.6	27.9	31.3	34.7	38.4	42.4	47.	51.7	
35							22.7	26.1	29.5	32.9	36.5	40.2	44.1	48.5	53.6	
36							24.0	27.5	31.1	34.7	38.4	42.2	46.1	50.3	55.1	
37							25.3	29.1	32.8	36.6	40.4	44.3	48.3	52.5	57.1	
38							26.7	30.6	34.6	38.6	42.6	46.6	51.2	55.	59.4	
39							28.1	32.3	36.4	40.6	44.8	49.1	53.3	57.6	62.1	
40								33.9	38.3	42.7	47.1	51.5	55.9	60.4	65.	
41								35.6	40.2	44.8	49.5	54.1	58.7	63.4	68.3	
42								37.4	42.2	47.0	51.9	56.7	61.6	66.4	71.	
43								39.2	44.2	49.3	54.4	59.4	64.5	69.6	74.	
44								41.0	46.3	51.6	56.9	62.2	67.5	72.8	78.	
45									48.5	54.0	59.5	65.1	70.6	76.2	81.9	
46									50.6	56.4	62.2	68.0	73.8	79.6	85.4	
47									52.9	58.9	64.9	71.0	77.1	83.1	89.1	
48									55.1	61.4	67.7	74.0	80.3	86.5	92.	
49									57.4	64.0	70.6	77.2	83.7	90.1	96.9	
50									59.8	66.7	73.5	80.3	87.1	93.	100.9	
BASIS TREES	3	0	21	56	25	26	15	3	1	2	2	1				

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNFORKED TREES
ASPEN
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.4	.9	1.3	1.8	2.3	2.7	3.2									20
8	.8	1.7	2.7	3.6	4.5	5.4	6.4	7.3								12
9	1.2	2.6	4.0	5.4	6.8	8.2	9.6	11.0	12.4							11
10		3.5	5.4	7.3	9.2	11.2	13.1	15.0	16.9							7
11		4.4	6.9	9.3	11.8	14.3	16.7	19.2	21.6	24.1						9
12		5.4	8.5	11.5	14.5	17.6	20.6	23.6	26.6	29.7						8
13		6.5	10.2	13.8	17.4	21.1	24.7	28.4	32.0	35.6	39.3					6
14		7.7	11.9	16.2	20.5	24.8	29.1	33.4	37.7	42.0	46.3					2
15			13.9	18.8	23.8	28.8	33.8	38.8	43.8	48.7	53.7	58.7				1
16			15.9	21.6	27.3	33.0	38.8	44.5	50.2	55.9	61.6	67.4				0
17			18.0	24.5	31.0	37.5	44.0	50.5	57.0	63.5	70.0	76.5	83.0			1
18			20.3	27.6	34.9	42.2	49.6	56.9	64.2	71.5	78.9	86.2	93.5			0
19			22.7	30.8	39.0	47.2	55.4	63.6	71.8	80.0	88.2	96.4	104.6	112.8		1
20				34.3	43.4	52.5	61.6	70.7	79.8	88.9	98.0	107.1	116.2	125.3		0
21				37.8	47.9	58.0	68.0	78.1	88.1	98.2	108.3	118.3	128.4	138.5	148.5	0
22				41.6	52.7	63.7	74.8	85.8	96.9	108.0	119.0	130.1	141.2	152.2	163.3	0
23				45.5	57.6	69.7	81.8	94.0	106.1	118.2	130.3	142.4	154.5	166.6	178.7	0
24				49.6	62.8	76.0	89.2	102.4	115.6	128.8	142.0	155.2	168.4	181.7	194.9	0
25					68.2	82.5	96.9	111.2	125.6	139.9	154.3	168.6	183.0	197.3	211.6	0
26					73.8	89.3	104.9	120.4	135.9	151.5	167.0	182.5	198.0	213.6	229.1	0
27					79.6	96.4	113.2	129.9	146.7	163.4	180.2	197.0	213.7	230.5	247.2	0
28					85.7	103.7	121.8	139.8	157.8	175.9	193.9	211.9	230.0	248.0	266.0	0
29					91.9	111.3	130.7	150.0	169.4	188.7	208.1	227.4	246.8	266.2	285.5	0
30						119.1	139.9	160.6	181.3	202.0	222.8	243.5	264.2	284.9	305.7	0
31						127.3	149.4	171.5	193.7	215.8	237.9	260.1	282.2	304.4	326.5	0
32						135.6	159.2	182.8	206.4	230.0	253.6	277.2	300.8	324.4	348.0	0
33						144.3	169.4	194.5	219.6	244.7	269.8	294.9	320.0	345.1	370.2	0
34						153.2	179.8	206.5	233.1	259.8	286.4	313.1	339.8	366.4	393.1	0
35							190.6	218.8	247.1	275.3	303.6	331.8	360.1	388.4	416.6	0
36							201.7	231.6	261.4	291.3	321.2	351.1	381.0	410.9	440.8	0
37							213.0	244.6	276.2	307.8	339.4	371.0	402.6	434.1	465.7	0
38							224.7	258.1	291.4	324.7	358.0	391.3	424.7	458.0	491.3	0
39							236.7	271.8	306.9	342.0	377.1	412.2	447.4	482.5	517.6	0
40								286.0	322.9	359.8	396.8	433.7	470.6	507.6	544.5	0
41								300.5	339.3	378.1	416.9	455.7	494.5	533.3	572.1	0
42								315.3	356.1	396.8	437.5	478.2	519.0	559.7	600.4	0
43								330.5	373.2	415.9	458.6	501.3	544.0	586.7	629.4	0
44								346.1	390.8	435.5	480.2	524.9	569.6	614.3	659.0	0
45									408.8	455.6	502.3	549.1	595.8	642.6	689.4	0
46									427.2	476.1	524.9	573.8	622.7	671.5	720.4	0
47									446.0	497.0	548.0	599.0	650.0	701.1	752.1	0
48									465.2	518.4	571.6	624.8	678.0	731.2	784.5	0
49									484.8	540.2	595.7	651.1	706.6	762.1	817.5	0
50									504.8	562.5	620.3	678.0	735.8	793.5	851.2	0
BASIS TREES	0	0	6	30	18	21	12	1	0	0	0	0	0	0	0	

NET CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES
ASPEN
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.3	.6	.9	1.3	1.8	2.3	3.0									29
8	.4	1.0	1.7	2.5	3.4	4.5	5.8	7.3								15
9	.6	1.4	2.3	3.4	4.8	6.4	8.3	10.6	12.4							12
10		1.6	2.8	4.2	5.9	8.0	10.5	13.6	16.9							11
11		1.9	3.2	4.8	6.9	9.3	12.4	16.1	20.7	24.1						12
12		2.0	3.5	5.3	7.5	10.3	13.8	18.2	23.7	29.7						13
13		2.1	3.6	5.6	8.0	11.0	14.9	19.8	25.9	33.7	39.3					7
14		2.2	3.7	5.7	8.3	11.4	15.5	20.7	27.4	36.0	46.3					3
15			3.8	5.8	8.3	11.6	15.8	21.2	28.3	37.4	49.3	58.7				2
16			3.8	5.8	8.3	11.6	15.8	21.2	28.4	37.9	50.3	66.7				
17			3.8	5.8	8.2	11.4	15.5	20.9	28.0	37.5	50.1	67.0	83.0			1
18			3.8	5.7	8.1	11.1	15.1	20.2	27.2	36.4	48.9	65.8	88.7			
19			3.9	5.7	8.0	10.9	14.6	19.5	26.0	34.9	47.0	63.4	86.0	113.8		1
20				5.8	7.9	10.6	14.1	18.7	24.8	33.1	44.4	60.1	81.8	113.0		
21				5.8	7.9	10.5	13.7	17.9	23.5	31.1	41.6	56.2	76.6	105.3	145.6	0
22				6.0	8.0	10.5	13.5	17.3	22.4	29.3	38.8	52.1	70.9	97.5	135.4	0
23				6.2	8.2	10.5	13.3	16.9	21.5	27.6	36.1	48.3	64.9	89.1	123.3	0
24				6.5	8.5	10.8	13.4	16.6	20.8	26.3	33.7	44.8	59.8	82.7	112.0	0
25					8.9	11.1	13.6	16.6	20.4	25.3	31.8	42.3	56.9	78.7	106.4	0
26					9.3	11.6	14.0	16.9	20.3	24.6	30.4	38.9	49.4	65.6	89.3	0
27					9.8	12.1	14.6	17.3	20.5	24.4	29.5	36.3	45.8	59.5	79.6	0
28					10.4	12.8	15.3	18.0	21.0	24.6	29.1	34.9	43.3	54.5	71.4	0
29					11.1	13.5	16.1	18.8	21.7	25.1	29.1	34.3	41.1	50.7	64.7	0
30						14.4	17.0	19.7	22.6	25.9	29.6	34.2	40.3	48.1	59.7	0
31						15.2	18.0	20.8	23.7	26.9	30.5	34.6	39.8	46.6	56.1	0
32						16.2	19.0	22.0	25.0	28.0	31.6	35.5	41.1	46.6	53.9	0
33						17.2	20.2	23.2	26.4	29.6	33.0	36.8	41.	46.7	53.9	0
34						18.2	21.4	24.6	27.9	31.2	34.6	38.3	41.4	47.1	53.9	
35							22.6	26.0	29.4	32.9	36.4	40.3	44.1	48.5	54.7	
36							23.9	27.5	31.1	34.7	38.4	42.3	46.1	51.	55.1	
37							25.3	29.0	32.8	36.6	40.4	44.3	48.	5 .5	5 .	
38							26.6	30.6	34.6	38.5	42.5	46.5	5 .	54.9	59.4	
39							28.1	32.2	36.4	40.6	44.7	49.	53.7	58.6	64.1	
40								33.9	38.3	42.6	47.1	51.4	55.9	61.4	65.	
41								35.6	40.2	44.8	49.4	54.	58.7	63.3	68.1	
42								37.4	42.2	47.1	51.8	56.6	61.5	66.4	71.7	
43								39.3	44.2	49.3	54.3	59.4	64.5	69.5	74.6	
44								41.0	46.3	51.6	56.9	62.2	67.5	72.8	78.1	
45									48.4	54.0	59.5	65.1	70.6	76.	81.	
46									50.6	56.4	62.2	68.1	73.8	79.5	85.	
47									52.8	58.9	64.9	71.0	77.	83.	89.	
48									55.1	61.4	67.8	74.0	80.	86.0	92.0	
49									57.4	64.0	70.6	77.1	83.7	90.	96.3	
50									59.8	66.6	73.5	80.4	87.3	94.	100.5	
BASIC TREES	2	8	21	35	29	6	19	3								

GROSS INTERNATIONAL BOARD FOOT VOLUME T[illegible] 6 INCH TOP DIB-UNBORKED [illegible]

ASPEN

SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS [illegible]
7	1.2	2.5	3.8	5.0	6.3	7.6	8.9									[illegible]
8	3.3	7.2	11.0	14.8	18.6	22.5	26.3	30.1								[illegible]
9	5.8	12.8	19.7	26.7	33.6	40.6	47.5	54.5	61.4							[illegible]
10		19.0	29.4	39.8	50.2	60.6	71.0	81.4	91.9							[illegible]
11		25.6	39.8	53.9	68.1	82.3	96.4	110.6	124.7	138.9						[illegible]
12		32.7	50.9	69.0	87.2	105.4	123.5	141.7	159.8	178.0						[illegible]
13		40.2	62.6	85.0	107.5	129.9	152.3	174.8	197.2	219.6	242.1					[illegible]
14		48.1	75.1	102.0	129.0	156.0	182.9	209.9	236.8	263.8	290.8					[illegible]
15			88.3	120.0	151.8	183.5	215.3	247.1	278.8	310.6	342.3	374.1				[illegible]
16			102.2	139.0	175.9	212.7	249.5	286.4	323.2	360.0	396.8	433.7				[illegible]
17			116.9	159.1	201.3	243.4	285.6	327.8	370.0	412.2	454.4	496.5	538.7			[illegible]
18			132.4	180.2	228.0	275.8	323.6	371.4	419.3	467.1	514.9	562.7	610.5			[illegible]
19			148.6	202.3	256.1	309.8	363.6	417.3	471.0	524.8	578.5	632.3	686.0	739.8		[illegible]
20				225.6	285.5	345.5	405.5	465.4	525.4	585.3	645.3	705.2	765.2	825.2		[illegible]
21				249.9	316.4	382.9	449.3	515.8	582.3	648.7	715.2	781.6	848.1	914.6	981.0	[illegible]
22				275.4	348.6	421.9	495.2	568.4	641.7	715.0	788.2	861.5	934.8	1008.1	1081.3	[illegible]
23				301.9	382.3	462.7	543.0	623.4	703.8	784.1	864.5	944.9	1025.2	1105.6	1186.0	[illegible]
24				329.6	417.4	505.1	592.9	680.7	768.4	856.2	944.0	1031.7	1119.5	1207.3	1295.1	[illegible]
25					453.8	549.3	644.8	740.3	835.7	931.2	1026.7	1122.1	1217.6	1313.1	1408.5	[illegible]
26					491.8	595.2	698.7	802.2	905.6	1009.1	1112.6	1216.0	1319.5	1423.0	1526.5	[illegible]
27					531.1	642.9	754.6	866.4	978.2	1090.0	1201.7	1313.5	1425.3	1537.1	1648.8	[illegible]
28					571.9	692.3	812.6	933.0	1053.4	1173.8	1294.1	1414.5	1534.9	1655.3	1775.7	[illegible]
29					614.1	743.4	872.7	1002.0	1131.2	1260.5	1389.8	1519.1	1648.4	1777.7	1907.0	[illegible]
30						796.2	934.7	1073.2	1211.7	1350.3	1488.8	1627.3	1765.8	1904.3	2042.8	[illegible]
31						850.9	998.9	1146.9	1294.9	1442.9	1591.0	1739.0	1887.0	2035.0	2183.0	[illegible]
32						907.2	1065.1	1222.9	1380.7	1538.6	1696.4	1854.3	2012.1	2170.0	2327.8	[illegible]
33						965.3	1133.3	1301.3	1469.3	1637.2	1805.2	1973.2	2141.1	2309.1	2477.1	[illegible]
34						1025.2	1203.6	1382.0	1560.4	1738.8	1917.2	2095.6	2274.1	2452.5	2630.9	[illegible]
35							1276.0	1465.1	1654.3	1843.4	2032.6	2221.7	2410.9	2600.0	2789.2	[illegible]
36							1350.4	1550.6	1750.8	1951.0	2151.2	2351.4	2551.6	2751.8	2952.0	[illegible]
37							1426.9	1638.4	1850.0	2061.5	2273.1	2484.6	2696.2	2907.7	3119.3	[illegible]
38							1505.5	1728.7	1951.9	2175.1	2398.3	2621.5	2844.7	3067.9	3291.1	[illegible]
39							1586.1	1821.3	2056.4	2291.6	2526.8	2762.0	2997.2	3232.3	3467.5	[illegible]
40								1916.2	2163.7	2411.2	2658.6	2906.1	3153.5	3401.0	3648.4	[illegible]
41								2013.6	2273.6	2533.7	2793.7	3053.7	3313.8	3573.8	3833.8	[illegible]
42								2113.3	2386.3	2659.2	2932.1	3205.0	3478.0	3750.9	4023.8	[illegible]
43								2215.4	2501.6	2787.7	3073.8	3359.9	3646.1	3932.2	4218.3	[illegible]
44								2319.9	2619.6	2919.2	3218.8	3518.4	3818.1	4117.7	4417.3	[illegible]
45									2740.2	3053.7	3367.1	3680.6	3994.0	4307.5	4620.9	[illegible]
46									2863.6	3191.2	3518.7	3846.3	4173.9	4501.4	4829.0	[illegible]
47									2989.7	3331.7	3673.7	4015.7	4357.7	4699.6	5041.6	[illegible]
48									3118.4	3475.2	3831.9	4188.6	4545.4	4902.1	5258.8	[illegible]
49									3249.9	3621.7	3993.4	4365.2	4737.0	5108.8	5480.5	[illegible]
50									3384.0	3771.2	4158.3	4545.4	4932.5	5319.7	5706.8	[illegible]
BASIS TREES	0	0	6	29	19	21	12	1	0	0	0	0	0	0	0	

NET INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB
ASPEN
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	ALL T
7	.1	.2	.3	.5	1.1	1.8	2.7									
8	.1	.3	.4	.8	2.4	4.6	7.1	10.								
9	.1	.2	.3	.8	3.8	7.6	12.1	17.3	23.1							
10		.1	.2	.9	5.2	10.9	17.7	25.	34.							
11		.1	.1	1.0	6.9	14.	23.8	34.3	45.9	58.						
12		.0	.1	1.2	8.7	18.	30.3	43.8	58.7	74.						
13		.0	.0	1.4	10.7	22.8	37.2	53.9	72.	91.	113.5					
14		.0	.0	1.7	12.8	27.	44.8	64.7	86.8	110.8	135.					
15			.0	2.0	15.1	32.	52.7	76.	102.	130.	160.	192.1				
16			.0	2.3	17.5	37.	61.1	88.	118.5	151.	186.					
17			.0	2.6	20.	42.	69.9	101.	135.6	173.	213.	256.9	298.7			
18			.	3.0	22.	48.	79.	114.	153.	196.	241.	289.	336.			
19			.0	3.4	25.5	54.	89.	128.	172.	220.	270.	324.	377.			
20				3.7	28.	61.	99.	143.	192.	245.	301.	361.	420.	483.		
21				4.2	31.5	67.	110.	159.	213.	272.	334.	400.	466.	537.		
22				4.6	34.	74.	121.	175.	235.	300.	368.	441.	513.	590.		
23				5.	38.	81.	133.	192.	258.	329.	404.	484.	563.	648.	734.	
24				5.5	41.5	88.5	145.	209.8	281.6	359.5	441.	528.	615.	708.	802.	
25					45.1	96.	157.6	228.	306.	391.	480.	575.1	670.	771.	873.	
26					48.9	104.	171.	247.	332.	424.	521.	624.	727.	837.	948.	
27					53.8	111.	184.6	267.	359.	459.	564.	676.	788.	907.	1028.	
28					56.9	119.	198.2	287.6	386.	494.	607.	728.	849.	977.	1107.	
29					1.	127.	212.	308.	414.	530.	651.	781.	911.	1049.	1189.	
30						135.	226.	329.	443.	567.	697.	836.	975.	1122.	1272.	
31						143.	241.	350.	472.	605.	744.	892.	1041.	1198.	1358.	
32						151.	255.	372.	501.	642.	790.	948.	1106.	1273.	1443.	
33						159.	270.	393.	530.	679.	836.	1003.	1170.	1348.	1528.	
34						168.	284.	415.	559.	717.	883.	1059.	1236.	1423.	1614.	
35						176.	299.	436.	588.	754.	929.	1115.	1301.	1498.	1699.	
36						184.	313.	458.	617.	792.	975.	1171.	1366.	1573.	1784.	
37						192.	328.	479.	646.	829.	1022.	1227.	1431.	1648.	1869.	
38						200.	342.	501.	675.	867.	1068.	1283.	1496.	1723.	1954.	
39						208.	357.	522.	704.	904.	1114.	1338.	1561.	1798.	2039.	
40						217.	371.	544.	733.	941.	1161.	1394.	1626.	1873.	2125.	
41						225.	386.	565.	762.	979.	1207.	1450.	1691.	1948.	2210.	
42						233.	400.	587.	791.	1016.	1253.	1506.	1756.	2023.	2295.	
43						241.	415.	608.	820.	1054.	1300.	1562.	1821.	2098.	2380.	
44						249.	429.	630.	849.	1091.	1346.	1617.	1886.	2173.	2466.	
45						257.	444.	651.	878.	1129.	1392.	1673.	1951.	2248.	2551.	
46						266.	458.	673.	907.	1166.	1439.	1729.	2016.	2323.	2637.	
47						274.	473.	694.	936.	1204.	1485.	1785.	2081.	2398.	2722.	
48						282.	487.	716.	965.	1241.	1531.	1841.	2146.	2473.	2808.	
49						290.	502.	737.	994.	1279.	1578.	1897.	2211.	2548.	2893.	
50						298.	516.	759.	1023.	1316.	1624.	1953.	2276.	2623.	2979.	
51						306.	531.	780.	1052.	1354.	1670.	2009.	2341.	2698.	3064.	
52						314.	545.	802.	1081.	1391.	1717.	2065.	2406.	2773.	3150.	
53						322.	560.	823.	1110.	1429.	1763.	2121.	2471.	2848.	3235.	
54						331.	574.	845.	1139.	1466.	1809.	2177.	2536.	2923.	3321.	
55						339.	589.	866.	1168.	1504.	1856.	2233.	2601.	2998.	3406.	
56						347.	603.	888.	1197.	1541.	1902.	2289.	2666.	3073.	3492.	
57						355.	618.	909.	1226.	1579.	1948.	2345.	2731.	3148.	3577.	
58						363.	632.	931.	1255.	1616.	1995.	2401.	2796.	3223.	3663.	
59						371.	647.	952.	1284.	1654.	2041.	2457.	2861.	3298.	3748.	
60						379.	661.	974.	1313.	1691.	2087.	2513.	2926.	3373.	3834.	

GROSS SCRIBNER BOARD FOOT VOLUME TO [illegible] INCH TOP DIB — [illegible]

ASPEN

SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	TA... TR...
7	.6	1.3	2.0	2.7	3.4	4.1	4.8										
8	2.1	4.4	6.8	9.2	11.5	13.9	16.3	18.7									
9	3.9	8.6	13.3	18.0	22.7	27.4	32.1	36.8	41.5								
10		13.6	21.0	28.5	36.0	43.4	50.9	58.3	65.8								
11		19.1	29.7	40.2	50.8	61.3	71.9	82.5	93.0	103.6							
12		25.1	39.1	53.0	67.0	81.0	94.9	108.9	122.8	136.8							
13		31.6	49.2	66.9	84.5	102.1	119.8	137.4	155.0	172.7	190.3						
14		38.5	60.1	81.7	103.2	124.8	146.4	167.9	189.5	211.1	232.7						
15			71.6	97.4	123.2	148.9	174.7	200.5	226.3	252.0	277.8	303.6					
16			83.9	114.1	144.3	174.6	204.8	235.0	265.2	295.5	325.7	355.9					
17			96.8	131.8	166.7	201.7	236.6	271.6	306.5	341.4	376.4	411.3	446.3				
18			110.5	150.4	190.3	230.2	270.2	310.1	350.0	389.9	429.8	469.8	509.7				
19			124.9	170.0	215.2	260.3	305.5	350.6	395.8	441.0	486.1	531.3	576.4	621.6			
20				190.6	241.3	291.9	342.6	393.2	443.9	494.5	545.2	595.9	646.5	697.2			
21				212.2	268.6	325.0	381.4	437.9	494.3	550.7	607.1	663.5	720.0	776.4	832.8		
22				234.7	297.2	359.6	422.1	484.5	547.0	609.4	671.9	734.3	796.8	859.2	921.7		
23				258.3	327.0	395.8	464.5	533.2	602.0	670.7	739.5	808.2	877.0	945.7	1014.5		
24				282.8	358.1	433.4	508.7	584.0	659.3	734.7	810.0	885.3	960.6	1035.9	1111.2		
25					390.5	472.6	554.8	636.9	719.0	801.2	883.3	965.5	1047.6	1129.7	1211.9		
26					424.1	513.4	602.6	691.8	781.1	870.3	959.5	1048.8	1138.0	1227.3	1316.5		
27					459.0	555.6	652.2	748.8	845.5	942.1	1038.7	1135.3	1231.9	1328.5	1425.1		
28					495.2	599.5	703.7	808.0	912.2	1016.4	1120.7	1224.9	1329.2	1433.4	1537.7		
29					532.7	644.8	757.0	869.1	981.3	1093.4	1205.6	1317.7	1429.9	1542.0	1654.2		
30						691.8	812.1	932.4	1052.8	1173.1	1293.4	1413.7	1534.1	1654.4	1774.7		
31						740.2	869.0	997.8	1126.6	1255.4	1384.1	1512.9	1641.7	1770.5	1899.2		
32						790.3	927.8	1065.3	1202.8	1340.3	1477.8	1615.3	1752.8	1890.3	2027.8		
33						841.9	988.4	1134.8	1281.3	1427.8	1574.3	1720.8	1867.3	2013.8	2160.3		
34						895.0	1050.8	1206.5	1362.3	1518.0	1673.8	1829.5	1985.3	2141.0	2296.8		
35							1115.0	1280.3	1445.6	1610.9	1776.2	1941.5	2106.7	2272.0	2437.3		
36							1181.1	1356.2	1531.3	1706.4	1881.5	2056.6	2231.7	2406.8	2581.9		
37							1249.0	1434.2	1619.4	1804.5	1989.7	2174.9	2360.1	2545.2	2730.4		
38							1318.8	1514.3	1709.8	1905.3	2100.9	2296.4	2491.9	2687.5	2883.0		
39							1390.3	1596.5	1802.7	2008.8	2215.0	2421.1	2627.3	2833.4	3039.6		
40								1680.8	1897.9	2114.9	2332.0	2549.0	2766.1	2983.1	3200.2		
41								1767.3	1995.5	2223.7	2451.9	2680.2	2908.4	3136.6	3364.8		
42								1855.8	2095.5	2335.1	2574.8	2814.5	3054.1	3293.8	3533.5		
43								1946.5	2197.9	2449.2	2700.6	2952.0	3203.4	3454.8	3706.2		
44								2039.2	2302.6	2566.0	2829.4	3092.7	3356.1	3619.5	3882.9		
45									2409.8	2685.4	2961.1	3236.7	3512.3	3788.0	4063.6		
46									2519.3	2807.5	3095.7	3383.8	3672.0	3960.2	4248.4		
47									2631.2	2932.2	3233.2	3534.2	3835.2	4136.2	4437.2		
48									2745.6	3059.6	3373.7	3687.8	4001.9	4315.9	4630.0		
49									2862.3	3189.7	3517.1	3844.6	4172.0	4499.4	4826.9		
50									2981.4	3322.5	3663.5	4004.6	4345.6	4686.7	5027.8		
BASIS TREES	0	0	0	4	12	11	10	1	0	0	0	0	0	0	0		

NET SCRIBNER BOARD FOOT VOLUME PER 1000 FOR DIX

ASPEN

SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.1	.1	.2	.3	.5	.8	1.1									21
8	.1	.2	.2	.4	1.1	2.0	3.1	4.4								12
9	.1	.1	.2	.5	1.8	3.5	5.6	8.0	10.7							11
10		.1	.1	.5	2.5	5.2	8.4	12.3	16.6							10
11		.0	.1	.5	3.4	7.1	11.7	17.1	23.2	30.0						15
12		.0	.0	.6	4.3	9.3	15.3	22.5	30.5	39.5						11
13		.0	.0	.8	5.4	11.6	19.3	28.3	38.5	49.7	62.0					7
14		.0	.0	.9	6.6	14.2	23.6	34.5	47.0	60.8	75.8					4
15			.0	1.1	7.9	16.9	28.1	41.2	56.1	72.5	90.5	109.8				2
16			.0	1.3	9.2	19.8	32.9	48.3	65.7	85.0	106.1	128.7				2
17			.0	1.5	10.6	22.9	38.0	55.8	75.9	98.2	122.6	148.7	176.5			1
18			.0	1.7	12.1	26.2	43.4	63.7	86.7	112.2	140.0	169.8	201.6			2
19			.0	1.9	13.7	29.6	49.1	72.0	98.0	126.9	158.3	192.1	228.2	265.8		1
20				2.1	15.4	33.2	55.1	80.8	110.0	142.3	177.5	215.4	255.7	298.2		1
21				2.4	17.1	36.9	61.3	89.9	122.4	158.5	197.7	239.9	284.7	332.2	381.5	
22				2.6	19.0	40.9	67.9	99.5	135.5	175.4	218.8	265.5	315.1	367.5	422.2	
23				2.9	20.9	45.0	74.7	109.5	149.1	193.0	240.8	292.2	346.8	404.5	464.7	
24				3.2	22.8	49.2	81.6	120.0	163.2	211.4	263.8	320.1	379.9	443.0	509.1	
25					24.9	53.7	89.2	130.8	178.1	230.5	287.6	349.0	414.3	483.1	555.3	
26					27.1	58.3	96.9	142.1	193.5	250.4	312.5	379.3	450.1	524.9	603.1	
27					29.3	63.1	104.9	153.8	209.4	271.1	338.3	410.4	487.1	568.1	652.9	
28					31.6	68.1	113.1	166.0	226.0	292.6	364.9	443.8	525.7	613.0	704.4	
29					34.0	73.3	121.7	178.5	243.1	314.6	392.6	476.4	565.1	659.5	757.8	
30						78.6	130.6	191.5	260.8	337.4	421.0	511.1	606.7	707.5	813.1	
31						84.1	139.7	205.0	279.1	361.0	450.7	547.0	649.3	757.0	870.1	
32						89.8	149.0	218.8	297.8	385.0	481.0	584.0	693.4	808.4	928.9	
33						95.6	158.4	233.1	317.0	410.8	512.7	622.4	738.7	861.1	989.7	
34						101.7	168.0	247.9	337.4	436.8	545.0	661.4	785.1	915.0	1051.7	
35							178.0	263.0	358.1	463.5	578.4	701.7	833.2	971.3	1116.4	
36							188.2	278.4	379.0	491.0	613.2	744.5	883.6	1029.8	1184.0	
37							198.6	294.0	401.1	519.0	647.6	786.0	933.4	1088.5	1251.2	
38							209.2	311.1	423.9	548.3	684.1	830.3	985.5	1149.1	1321.1	
39							220.0	328.2	446.9	578.0	721.3	875.5	1039.1	1211.7	1392.4	
40							231.0	345.5	470.4	608.2	758.9	921.5	1094.1	1275.8	1466.1	
41								363.1	494.2	639.0	796.9	968.0	1149.5	1340.4	1540.2	
42								381.0	518.3	671.0	836.5	1015.9	1206.3	1406.5	1616.7	
43								399.2	543.0	703.2	876.4	1064.2	1263.6	1473.2	1693.5	
44								417.8	568.1	735.8	917.0	1113.0	1321.4	1540.4	1770.8	
45									593.6	768.9	958.1	1163.2	1380.6	1609.1	1848.6	
46									619.5	802.4	999.7	1213.8	1440.8	1678.2	1927.9	
47									645.8	836.4	1041.8	1264.8	1501.4	1749.6	2010.0	
48									672.4	870.8	1084.3	1316.3	1562.4	1821.3	2092.4	
49									699.3	905.6	1127.3	1368.2	1623.8	1893.2	2175.1	
50									726.5	940.7	1170.8	1420.5	1685.6	1965.4	2258.1	
TOTAL																

TOTAL STEM GROSS CUBIC FOOT VOLUME (HUNDRED)

AREA BID

LOCATION NO.

DBH CLASS	HEIGHT CLASS														
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
1	.2														
2	.3	.4													
3	.4	.5	.7												
4	.5	.8	1.1	1.4											
5	.7	1.1	1.6	2.1	2.5										
6	.9	1.5	2.2	2.9	3.5	4.2									
7	1.1	2.0	2.9	3.8	4.7	5.6	6.5								
8	1.4	2.6	3.7	4.9	6.1	7.3	8.5	9.6							
9	1.7	3.2	4.7	6.2	7.7	9.2	10.6	12.1	13.6						
10		3.9	5.7	7.6	9.4	11.3	13.1	14.9	16.8						
11		4.7	6.9	9.1	11.3	13.6	15.8	18.0	20.2	22.5					
12		5.5	8.2	10.8	13.5	16.1	18.8	21.4	24.1	26.7					
13		6.4	9.5	12.6	15.8	18.9	22.0	25.1	28.2	31.3	34.4				
14		7.4	11.0	14.6	18.2	21.8	25.5	29.1	32.7	36.3	39.9				
15			12.6	16.8	20.9	25.1	29.2	33.3	37.5	41.6	45.7	49.9			
16			14.3	19.1	23.8	28.5	33.2	37.9	42.6	47.3	52.0	56.7			
17			16.2	21.5	26.8	32.1	37.4	42.8	48.1	53.4	58.7	64.0			
18			18.1	24.1	30.0	36.0	41.9	47.9	53.9	59.8	65.8	71.8			
19			20.1	26.8	33.4	40.1	46.7	53.3	60.0	66.6	73.3	79.9	86.6	93.2	
20				29.7	37.0	44.4	51.7	59.1	66.4	73.8	81.2	88.5	95.9	103.3	
21				32.7	40.8	48.9	57.0	65.1	73.2	81.4	89.5	97.6	105.7	113.8	121.9
22				35.8	44.7	53.6	62.5	71.5	80.4	89.3	98.2	107.1	116.0	124.9	133.8
23				39.1	48.9	58.6	68.3	78.1	87.8	97.5	107.3	117.0	126.7	136.5	146.2
24				42.6	53.2	63.8	74.4	85.0	95.6	106.2	116.8	127.4	138.0	148.6	159.2
25					57.7	69.2	80.7	92.2	103.7	115.2	126.7	138.2	149.7	161.2	172.7
26					62.4	74.8	87.3	99.7	112.2	124.6	137.0	149.5	161.9	174.4	186.8
27					67.3	80.7	94.1	107.5	120.9	134.3	147.8	161.2	174.6	188.0	201.4
28					72.3	86.8	101.2	115.6	130.0	144.5	158.9	173.3	187.7	202.1	216.6
29					77.6	93.1	108.5	124.0	139.5	155.0	170.4	185.9	201.4	216.8	232.3
30					83.0	99.6	116.1	132.7	149.2	165.8	182.4	198.9	215.5	232.1	248.6
31						106.3	124.0	141.7	159.3	177.0	194.7	212.4	230.1	247.8	265.4
32						113.3	132.1	150.9	169.8	188.6	207.5	226.3	245.1	263.9	282.8
33						120.4	140.5	160.5	180.5	200.6	220.6	240.7	260.7	280.7	300.8
34						127.8	149.1	170.4	191.6	212.9	234.2	255.4	276.7	298.0	319.3
35						135.4	158.0	180.5	203.1	225.6	248.1	270.7	293.2	315.8	338.3
36							167.1	191.0	214.8	238.7	262.5	286.4	310.2	334.1	357.9
37							176.5	201.7	226.9	252.1	277.3	302.5	327.7	353.0	378.0
38							186.2	212.8	239.3	265.9	292.5	319.0	345.6	372.1	398.7
39							196.1	224.1	252.1	280.1	308.1	336.0	364.0	392.0	420.0
40							206.3	235.7	265.2	294.6	324.0	353.5	382.9	412.4	441.8
41								247.6	278.6	309.5	340.4	371.4	402.3	433.2	464.2
42								259.9	292.3	324.8	357.2	389.7	422.2	454.6	487.1
43								272.4	306.4	340.4	374.4	408.5	442.5	476.5	510.5
44								285.2	320.8	356.4	392.0	427.7	463.3	498.9	534.5
45								298.3	335.5	372.8	410.1	447.3	484.6	521.8	559.1
46									350.6	389.5	428.5	467.4	506.3	545.3	584.2
47									366.0	406.7	447.3	487.9	528.6	569.3	609.9
48									381.7	424.1	466.5	508.9	551.3	593.7	636.1
49									397.8	442.0	486.2	530.3	574.5	618.7	662.9
50									414.2	460.2	506.2	552.2	598.2	644.2	690.2

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
1	.2															
2	.3	.4														
3	.4	.5	.7													
4	.5	.8	1.1	1.4												
5	.7	1.1	1.6	2.0	2.5											
6	.9	1.5	2.2	2.8	3.5	4.2										
7	1.1	2.0	2.9	3.8	4.7	5.6	6.5									
8	1.4	2.5	3.7	4.9	6.0	7.2	8.4	9.5								
9	1.7	3.1	4.6	6.1	7.6	9.0	10.5	12.0	13.4							
10		3.8	5.6	7.4	9.2	11.0	12.8	14.6	16.5							
11		4.6	6.7	8.9	11.1	13.2	15.4	17.6	19.8	21.9						
12		5.3	7.9	10.5	13.0	15.6	18.0	20.8	23.3	25.9						
13		6.2	9.2	12.2	15.2	18.2	21.1	24.1	27.1	30.1	33.1					
14		7.1	10.5	14.0	17.4	20.8	24.3	27.7	31.2	34.6	38.0					
15			11.9	15.8	19.8	23.7	27.6	31.5	35.4	39.3	43.2	47.1				
16			13.4	17.8	22.2	26.6	31.0	35.4	39.8	44.2	48.6	53.0				
17			14.9	19.8	24.8	29.7	34.6	39.5	44.4	49.3	54.2	59.2	64.1			
18			16.5	21.9	27.4	32.8	38.2	43.7	49.1	54.6	60.0	65.4	70.9			
19			18.1	24.1	30.1	36.0	42.0	48.0	54.0	59.9	65.9	71.9	77.9	83.8		
20				26.3	32.8	39.3	45.9	52.4	58.9	65.4	71.9	78.5	85.0	91.5		
21				28.5	35.6	42.7	49.8	56.8	63.9	71.0	78.1	85.2	92.3	99.3	106.4	
22				30.8	38.4	46.1	53.7	61.4	69.0	76.7	84.3	91.9	99.6	107.2	114.9	
23				33.1	41.3	49.5	57.7	65.9	74.1	82.4	90.6	98.8	107.1	115.3	123.5	
24				35.4	44.1	52.9	61.7	70.5	79.3	88.1	96.9	105.7	114.5	123.3	132.1	
25					47.1	56.4	65.8	75.2	84.5	93.9	103.2	112.7	122.0	131.4	140.8	
26					50.2	59.9	69.9	79.8	89.8	99.7	109.7	119.7	129.6	139.6	149.5	
27					52.9	63.4	74.0	84.5	95.1	105.6	116.1	126.7	137.2	147.8	158.3	
28					55.8	67.0	78.1	89.3	100.4	111.5	122.6	133.8	144.9	156.	167.1	
29					58.8	70.5	82.3	94.0	105.7	117.4	129.2	140.9	152.6	164.3	176.1	
30						74.1	86.4	98.8	111.1	123.4	135.7	148.1	160.4	172.7	185.	
31						77.7	90.7	103.6	116.5	129.4	142.4	155.3	168.2	181.2	194.1	
32						81.4	94.9	108.5	[illegible]	135.5	149.1	162.6	176.2	189.	[illegible]	
33						85.1	99.2	113.4	127.5	141.7	155.9	170.1	184.3	198.	[illegible]	
34						88.8	103.6	118.4	133.2	148.0	162.8	177.5	192.	[illegible]	[illegible]	
35							108.1	123.5	138.9	154.3	169.7	185.1	[illegible]	[illegible]	[illegible]	
36							112.6	128.6	144.7	160.8	176.8	192.9	[illegible]	[illegible]	[illegible]	
37							117.1	133.9	150.6	167.4	184.1	[illegible]	[illegible]	[illegible]	[illegible]	
38							121.9	139.3	156.7	174.1	191.5	[illegible]	[illegible]	[illegible]	[illegible]	
39							126.7	144.8	162.9	180.9	199.	[illegible]	[illegible]	[illegible]	[illegible]	
40								150.4	169.2	188.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
41								156.2	175.7	195.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
42								162.1	182.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
43								168.	189.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
44								174.1	195.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
45									202.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
46									210.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
47									218.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
48									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
49									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
50									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
TOTAL									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNMARKED TREES
WHITE FIR
LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	TOT
5	.5	.8	1.1	1.4	1.7											5
6	.7	1.2	1.8	2.3	2.8	3.3										6
7	.9	1.7	2.4	3.2	4.0	4.8	5.6									7
8	1.1	2.1	3.2	4.3	5.4	6.5	7.5	8.6								1
9	1.3	2.7	4.1	5.5	6.9	8.3	9.7	11.1	12.5							5
10		3.3	5.0	6.8	8.6	10.3	12.1	13.8	15.6							1
11		3.9	6.1	8.3	10.4	12.6	14.7	16.9	19.0	21.2						1
12		4.7	7.2	9.8	12.4	15.0	17.6	20.2	22.7	25.3						1
13		5.4	8.5	11.5	14.6	17.6	20.7	23.7	26.8	29.8	32.9					4
14		6.3	9.8	13.4	16.9	20.5	24.0	27.6	31.1	34.7	38.2					2
15			11.2	15.3	19.4	23.5	27.6	31.7	35.8	39.9	43.9	48.0				1
16			12.8	17.4	22.1	26.8	31.4	36.1	40.7	45.4	50.1	54.7				5
17			14.4	19.7	24.9	30.2	35.5	40.8	46.0	51.3	56.6	61.8	67.1			2
18			16.1	22.0	28.0	33.9	39.8	45.7	51.6	57.5	63.5	69.4	75.3			7
19			17.9	24.5	31.1	37.7	44.3	50.9	57.5	64.1	70.7	77.3	83.9	90.5		16
20				27.2	34.5	41.8	49.1	56.5	63.8	71.1	78.4	85.7	93.1	100.4		3
21				29.9	38.0	46.1	54.2	62.2	70.3	78.4	86.5	94.6	102.6	110.7	118.8	10
22				32.8	41.7	50.6	59.5	68.3	77.2	86.1	94.9	103.8	112.7	121.5	130.4	11
23				35.9	45.6	55.3	65.0	74.7	84.4	94.1	103.8	113.5	123.2	132.9	142.6	5
24				39.1	49.6	60.2	70.8	81.3	91.9	102.4	113.0	123.6	134.1	144.7	155.3	14
25					53.8	65.3	76.8	88.2	99.7	111.2	122.6	134.1	145.6	157.0	168.5	12
26					58.2	70.6	83.0	95.4	107.8	120.2	132.7	145.1	157.5	169.9	182.3	10
27					62.8	76.1	89.5	102.9	116.3	129.7	143.1	156.4	169.8	183.2	196.6	12
28					67.5	81.9	96.3	110.7	125.1	139.5	153.9	168.3	182.7	197.1	211.4	3
29					72.4	87.8	103.3	118.7	134.2	149.6	165.1	180.5	195.9	211.4	226.8	2
30						94.0	110.5	127.0	143.6	160.1	176.6	193.2	209.7	226.2	242.8	3
31						100.3	118.0	135.6	153.3	171.0	188.6	206.3	223.9	241.6	259.2	6
32						106.9	125.7	144.5	163.3	182.2	201.0	219.8	238.6	257.4	276.2	2
33						113.7	133.7	153.7	173.7	193.7	213.7	233.7	253.8	273.8	293.8	1
34						120.7	141.9	163.1	184.4	205.6	226.9	248.1	269.4	290.6	311.9	2
35							150.4	172.9	195.4	217.9	240.4	262.9	285.5	308.0	330.5	0
36							159.1	182.9	206.7	230.5	254.4	278.2	302.0	325.8	349.7	0
37							168.0	193.2	218.4	243.5	268.7	293.9	319.0	344.2	369.4	0
38							177.2	203.8	230.3	256.9	283.4	310.0	336.5	363.0	389.6	0
39							186.7	214.6	242.6	270.5	298.5	326.5	354.4	382.4	410.4	0
40								225.8	255.2	284.6	314.0	343.4	372.9	402.3	431.7	0
41								237.2	268.1	299.0	329.9	360.8	391.7	422.6	453.5	0
42								248.9	281.3	313.8	346.2	378.6	411.1	443.5	475.9	0
43								260.9	294.9	328.9	362.9	396.9	430.9	464.9	498.9	0
44								273.1	308.7	344.3	379.9	415.5	451.1	486.8	522.4	0
45									322.9	360.2	397.4	434.6	471.9	509.1	546.4	0
46									337.4	376.3	415.3	454.2	493.1	532.0	570.9	0
47									352.2	392.9	433.5	474.1	514.8	555.4	596.0	0
48									367.4	409.8	452.1	494.5	536.9	579.3	621.6	0
49									382.8	427.0	471.2	515.3	559.5	603.7	647.8	0
50									398.6	444.6	490.6	536.6	582.6	628.5	674.5	0
BASIS TREES	0	0	3	7	12	29	36	32	24	12	7	2	1	0	0	

DBH CLASS	HEIGHT CLASS															BASIS TREES
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
5	.5	.8	1.1	1.4	1.7											2
6	.7	1.2	1.7	2.3	2.8	3.3										1
7	.9	1.7	2.4	3.2	4.0	4.8	5.6									2
8	1.1	2.1	3.2	4.3	5.3	6.4	7.5	8.5								1
9	1.3	2.7	4.0	5.4	6.8	8.2	9.6	10.9	12.3							2
10		3.2	5.0	6.7	8.4	10.1	11.9	13.6	15.3							2
11		3.8	6.0	8.1	10.2	12.3	14.4	16.5	18.6	20.7						1
12		4.5	7.0	9.5	12.0	14.5	17.0	19.5	22.0	24.5						1
13		5.2	8.2	11.1	14.0	17.0	19.9	22.8	25.8	28.7	31.6					5
14		6.0	9.4	12.8	16.1	19.5	22.9	26.3	29.7	33.1	36.5					1
15			10.6	14.5	18.4	22.2	26.1	29.9	33.8	37.7	41.5	45.4				2
16			11.9	16.3	20.7	25.0	29.4	33.7	38.1	42.4	46.8	51.2				1
17			13.3	18.2	23.0	27.9	32.8	37.7	42.5	47.4	52.3	57.1	62.0			3
18			14.7	20.1	25.5	30.9	36.3	41.7	47.1	52.5	57.9	63.3	68.7			3
19			16.1	22.1	28.0	34.0	39.9	45.8	51.8	57.7	63.7	69.6	75.5	81.5		1
20				24.1	30.6	37.1	43.6	50.1	56.5	63.0	69.5	76.0	82.5	89.0		1
21				26.1	33.2	40.2	47.3	54.4	61.4	68.5	75.5	82.6	89.6	96.7	103.7	1
22				28.2	35.8	43.5	51.1	58.7	66.3	73.9	81.6	89.2	96.8	104.4	112.0	2
23				30.3	38.5	46.7	54.9	63.1	71.3	79.5	87.7	95.9	104.1	112.3	120.4	1
24				32.4	41.2	50.0	58.7	67.5	76.3	85.1	93.8	102.6	111.4	120.1	128.9	2
25					43.9	53.3	62.6	72.0	81.3	90.7	100.0	109.4	118.7	128.1	137.4	2
26					46.6	56.6	66.5	76.5	86.4	96.3	106.3	116.2	126.2	136.1	146.0	1
27					49.4	59.9	70.4	81.0	91.5	102.0	112.5	123.1	133.6	144.1	154.7	3
28					52.1	63.3	74.4	85.5	96.6	107.7	118.9	130.0	141.1	152.2	163.4	3
29					54.9	66.6	78.3	90.1	101.8	113.5	125.2	136.9	148.6	160.4	172.1	3
30						70.0	82.3	94.7	107.0	119.3	131.6	143.9	156.2	168.6	180.9	1
31						73.4	86.4	99.3	112.2	125.1	138.1	151.0	163.9	176.8	189.8	1
32						76.9	90.4	104.0	117.5	131.1	144.6	158.1	171.7	185.2	198.7	2
33						80.4	94.6	108.7	122.9	137.0	151.2	165.4	179.5	193.7	207.8	2
34						84.0	98.7	113.5	128.3	143.1	157.9	172.7	187.5	202.3	217.1	2
35							103.0	118.4	133.8	149.3	164.7	180.1	195.5	211.0	226.4	1
36							107.3	123.4	139.5	155.5	171.6	187.7	203.8	219.8	235.9	1
37							111.7	128.5	145.2	161.9	178.7	195.4	212.1	228.9	245.6	2
38							116.2	133.6	151.0	168.5	185.9	203.3	220.7	238.1	255.5	2
39							120.8	138.9	157.0	175.1	193.2	211.3	229.4	247.5	265.6	2
40								144.3	163.1	182.0	200.8	219.6	238.4	257.1	275.9	2
41								149.9	169.4	189.0	208.5	228.1	247.6	267.1	286.6	2
42								155.6	175.9	196.1	216.4	236.7	257.0	277.2	297.5	2
43								161.4	182.5	203.5	224.6	245.6	266.6	287.7	308.7	2
44								167.4	189.3	211.1	232.9	254.7	276.6	298.4	320.3	2
45									196.2	218.9	241.5	264.1	286.8	309.4	332.1	2
46									203.4	226.9	250.3	273.8	297.2	320.7	344.1	2
47									211.8	235.1	259.4	283.7	308.0	332.3	356.5	2
48									218.3	243.5	268.7	293.9	319.1	344.3	369.5	2
49									226.1	252.2	278.3	304.4	330.5	356.6	382.6	2
50									234.1	261.1	288.1	315.2	342.2	369.2	396.2	2
BASIS TREES	2	1	2	3	4	4	10	5	7	4	4	5	1	1	1	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES-UNBORKED TREES
WHITE FIR
LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.6	1.1	1.6	2.2	2.7	3.2	3.7									0
8	.8	1.7	2.5	3.4	4.2	5.0	5.9	6.7								1
9	1.1	2.3	3.5	4.7	5.8	7.0	8.2	9.4	10.6							0
10		2.9	4.5	6.1	7.6	9.2	10.8	12.3	13.9							1
11		3.6	5.6	7.6	9.5	11.5	13.5	15.5	17.5	19.5						1
12		4.3	6.8	9.2	11.6	14.0	16.5	18.9	21.3	23.7						1
13		5.1	8.0	10.9	13.8	16.8	19.7	22.6	25.5	28.4	31.3					4
14		6.0	9.4	12.8	16.2	19.7	23.1	26.5	29.9	33.3	36.7					3
15			10.9	14.8	18.8	22.7	26.7	30.7	34.6	38.6	42.6	46.5				1
16			12.4	17.0	21.5	26.0	30.6	35.1	39.7	44.2	48.8	53.3				5
17			14.1	19.2	24.4	29.5	34.7	39.9	45.0	50.2	55.3	60.5	65.7			9
18			15.8	21.6	27.4	33.2	39.1	44.9	50.7	56.5	62.3	68.1	73.9			7
19			17.6	24.1	30.6	37.1	43.6	50.1	56.6	63.1	69.6	76.1	82.6	89.1		16
20				26.8	34.0	41.2	48.5	55.7	62.9	70.1	77.4	84.6	91.8	99.0		3
21				29.6	37.6	45.6	53.5	61.5	69.5	77.5	85.5	93.5	101.5	109.4	117.4	10
22				32.5	41.3	50.1	58.9	67.6	76.4	85.2	94.0	102.8	111.5	120.3	129.1	11
23				35.6	45.2	54.8	64.4	74.0	83.6	93.3	102.9	112.5	122.1	131.7	141.3	5
24				38.7	49.2	59.7	70.2	80.7	91.2	101.7	112.1	122.6	133.1	143.6	154.1	14
25					53.5	64.8	76.2	87.6	99.0	110.4	121.8	133.2	144.6	156.0	167.4	12
26					57.8	70.2	82.5	94.8	107.2	119.5	131.9	144.2	156.5	168.9	181.2	10
27					62.4	75.7	89.0	102.3	115.7	129.0	142.3	155.6	168.9	182.2	195.5	12
28					67.1	81.5	95.8	110.1	124.5	138.8	153.1	167.4	181.8	196.1	210.4	8
29					72.0	87.4	102.8	118.2	133.6	149.0	164.3	179.7	195.1	210.5	225.9	3
30						93.6	110.1	126.5	143.0	159.5	175.9	192.4	208.9	225.3	241.8	3
31						100.0	117.6	135.2	152.7	170.3	187.9	205.5	223.1	240.7	258.3	6
32						106.5	125.3	144.1	162.8	181.6	200.3	219.1	237.8	256.6	275.4	2
33						113.3	133.3	153.2	173.2	193.1	213.1	233.1	253.0	273.0	292.9	1
34						120.3	141.5	162.7	183.9	205.1	226.3	247.5	268.7	289.8	311.0	2
35							150.0	172.4	194.9	217.4	239.8	262.3	284.8	307.2	329.7	0
36							158.7	182.5	206.2	230.0	253.8	277.6	301.3	325.1	348.9	0
37							167.7	192.8	217.9	243.0	268.1	293.2	318.4	343.5	368.6	0
38							176.9	203.4	229.9	256.4	282.9	309.4	335.9	362.3	388.8	0
39							186.3	214.2	242.1	270.1	298.0	325.9	353.8	381.7	409.6	0
40								225.4	254.7	284.1	313.5	342.9	372.2	401.6	431.0	0
41								236.8	267.7	298.5	329.4	360.3	391.1	422.0	452.9	0
42								248.5	280.9	313.3	345.7	378.1	410.5	442.9	475.3	0
43								260.5	294.5	328.4	362.4	396.3	430.3	464.3	498.2	0
44								272.8	308.3	343.9	379.5	415.0	450.6	486.1	521.7	0
45									322.5	359.7	396.9	434.1	471.3	508.5	545.7	0
46									337.1	375.9	414.8	453.7	492.6	531.4	570.3	0
47									351.9	392.5	433.1	473.6	514.2	554.8	595.4	0
48									367.0	409.4	451.7	494.0	536.4	578.7	621.1	0
49									382.5	426.6	470.7	514.9	559.0	603.1	647.2	0
50									398.3	444.2	490.2	536.1	582.1	628.0	674.0	0
BASIS																

WHITE FIR
LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.6	1.1	1.6	2.1	2.6	3.2	3.7									2
8	.8	1.7	2.5	3.3	4.2	5.0	5.8	6.6								1
9	1.1	2.2	3.4	4.6	5.8	6.9	8.1	9.3	10.5							2
10		2.9	4.4	5.9	7.5	9.0	10.6	12.1	13.6							2
11		3.5	5.4	7.4	9.3	11.2	13.2	15.1	17.0	19.0						1
12		4.2	6.6	8.9	11.3	13.6	16.0	18.3	20.7	23.0						1
13		4.9	7.7	10.5	13.3	16.1	18.9	21.7	24.5	27.3	30.1					5
14		5.7	9.0	12.2	15.5	18.7	22.0	25.3	28.5	31.8	35.0					1
15			10.3	14.0	17.7	21.5	25.2	29.0	32.7	36.4	40.2	43.9				2
16			11.6	15.8	20.1	24.3	28.6	32.8	37.1	41.3	45.6	49.8				1
17			13.0	17.8	22.5	27.3	32.0	36.8	41.6	46.3	51.1	55.9	60.6			3
18			14.4	19.7	25.0	30.3	35.6	40.9	46.2	51.5	56.8	62.1	67.4			2
19			15.9	21.7	27.6	33.4	39.2	45.1	50.9	56.8	62.6	68.5	74.3	80.2		1
20				23.7	30.1	36.5	42.9	49.3	55.7	62.2	68.6	75.0	81.4	87.8		2
21				25.8	32.8	39.7	46.7	53.7	60.6	67.6	74.6	81.5	88.5	95.5	102.4	1
22				27.9	35.4	43.0	50.5	58.0	65.6	73.1	80.7	88.2	95.7	103.3	110.8	2
23				30.0	38.1	46.2	54.4	62.5	70.6	78.7	86.8	94.9	103.0	111.2	119.3	1
24				32.1	40.8	49.5	58.2	66.9	75.6	84.3	93.0	101.7	110.4	119.1	127.8	3
25					43.5	52.8	62.1	71.4	80.7	90.0	99.3	108.5	117.8	127.1	136.4	2
26					46.3	56.2	66.0	75.9	85.8	95.6	105.5	115.4	125.2	135.1	145.0	1
27					49.0	59.5	70.0	80.4	90.9	101.3	111.8	122.3	132.7	143.2	153.6	3
28					51.8	62.9	73.9	85.0	96.0	107.1	118.1	129.2	140.2	151.3	162.3	3
29					54.6	66.2	77.9	89.5	101.2	112.8	124.5	136.1	147.8	159.4	171.1	2
30						69.6	81.9	94.1	106.4	118.6	130.9	143.2	155.4	167.7	179.9	1
31						73.1	85.9	98.8	111.6	124.5	137.4	150.2	163.1	176.0	188.8	1
32						76.5	90.0	103.5	117.0	130.4	143.9	157.4	170.9	184.3	197.8	3
33						80.0	94.1	108.2	122.3	136.4	150.5	164.6	178.7	192.8	206.9	2
34						83.6	98.3	113.0	127.8	142.5	157.2	171.9	186.7	201.4	216.1	2
35							102.6	117.9	133.2	148.7	164.0	179.4	194.8	210.1	225.5	1
36							106.9	122.9	138.9	154.9	171.0	187.0	203.0	219.0	235.0	1
37							111.3	128.0	144.7	161.3	178.0	194.7	211.4	228.1	244.7	3
38							115.8	133.2	150.5	167.9	185.3	202.6	219.9	237.3	254.6	3
39							120.4	138.5	156.5	174.6	192.6	210.6	228.7	246.7	264.8	2
40								143.9	162.6	181.4	200.1	218.9	237.7	256.4	275.2	3
41								149.4	168.9	188.4	207.9	227.4	246.8	266.3	285.8	3
42								155.2	175.4	195.5	215.8	236.0	256.3	276.5	296.7	3
43								161.0	182.0	203.0	224.0	245.0	265.9	286.9	307.9	3
44								167.0	188.8	210.6	232.3	254.1	275.9	297.7	319.4	1
45									195.8	218.4	240.9	263.5	286.1	308.6	331.2	3
46									203.0	226.4	249.8	273.2	296.6	320.0	343.4	3
47									210.3	234.6	258.9	283.1	307.4	331.7	356.0	3
48									217.9	243.1	268.2	293.3	318.5	343.6	368.8	3
49									225.7	251.8	277.8	303.8	329.9	355.9	381.9	3
50									233.7	260.7	287.7	314.6	341.6	368.5	395.5	3
BASIS TREES	0	1	2	3	3	5	12	5	7	3	4	1	2	1		

GROSS INTERNATIONAL BOARD FOOT VOLUME IN 4 INCH TOP DIB-UNFORKED TREES

WHITE FIR

LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	SAMPLE TREES
7	.7	1.3	1.8	2.4	3.0	3.6	4.2									2
8	1.8	3.7	5.6	7.4	9.3	11.2	13.0	14.9								1
9	3.2	6.7	10.3	13.8	17.4	20.9	24.5	28.0	31.5							2
10		10.3	15.8	21.3	26.9	32.4	37.9	43.5	49.0							5
11		14.2	22.0	29.8	37.6	45.4	53.2	61.0	68.8	76.6						1
12		18.5	28.8	39.2	49.5	59.8	70.1	80.5	90.8	101.1						1
13		23.2	36.3	49.4	62.5	75.6	88.7	101.8	114.9	128.0	141.0					2
14		28.3	44.4	60.5	76.6	92.7	108.8	124.9	140.9	157.0	173.1					1
15			53.1	72.4	91.7	111.0	130.4	149.7	169.0	188.4	207.7	227.0				3
16			62.3	85.1	107.9	130.7	153.5	176.3	199.1	221.9	244.7	267.5				1
17			72.2	98.7	125.2	151.7	178.2	204.7	231.2	257.7	284.2	310.7	337.1			0
18			82.7	113.1	143.5	174.0	204.4	234.8	265.2	295.6	326.0	356.5	386.9			1
19			93.8	128.4	162.9	197.5	232.1	266.7	301.2	335.8	370.4	404.9	439.5	474.1		0
20				144.5	183.4	222.4	261.3	300.3	339.2	378.2	417.1	456.1	495.0	534.0		1
21				161.4	204.9	248.5	292.0	335.6	379.2	422.7	466.3	509.8	553.4	597.0	640.5	1
22				179.1	227.5	275.9	324.3	372.7	421.1	469.5	517.9	566.3	614.7	663.1	711.5	1
23				197.7	251.1	304.6	358.1	411.5	465.0	518.5	571.9	625.4	678.9	732.3	785.8	0
24				217.1	275.8	334.6	393.4	452.1	510.9	569.6	628.4	687.2	745.9	804.7	863.4	3
25					301.6	365.9	430.2	494.5	558.8	623.0	687.3	751.6	815.9	880.2	944.5	2
26					328.4	398.5	468.5	538.6	608.6	678.6	748.7	818.7	888.7	958.8	1028.8	1
27					356.3	432.4	508.4	584.4	660.4	736.4	812.4	888.5	964.5	1040.5	1116.5	0
28					385.3	467.5	549.8	632.0	714.2	796.4	878.7	960.9	1043.1	1125.4	1207.6	3
29					415.3	504.0	592.7	681.3	770.0	858.7	947.3	1036.0	1124.7	1213.3	1302.0	2
30						541.8	637.1	732.4	827.8	923.1	1018.4	1113.8	1209.1	1304.4	1399.8	1
31						580.8	683.0	785.3	887.5	989.7	1092.0	1194.2	1296.4	1398.7	1500.9	1
32						621.2	730.5	839.9	949.2	1058.6	1168.0	1277.3	1386.7	1496.0	1605.4	0
33						662.8	779.5	896.2	1012.9	1129.7	1246.4	1363.1	1479.8	1596.5	1713.2	2
34						705.8	830.0	954.3	1078.6	1202.9	1327.2	1451.5	1575.8	1700.1	1824.4	2
35							882.1	1014.2	1146.3	1278.4	1410.6	1542.7	1674.8	1806.9	1939.0	1
36							935.7	1075.8	1216.0	1356.1	1496.3	1636.5	1776.6	1916.8	2056.9	1
37							990.8	1139.2	1287.6	1436.1	1584.5	1732.9	1881.4	2029.8	2178.2	0
38							1047.4	1204.4	1361.3	1518.2	1675.1	1832.1	1989.0	2145.9	2302.9	0
39							1105.6	1271.3	1436.9	1602.6	1768.2	1933.9	2099.6	2265.2	2430.9	0
40								1339.9	1514.5	1689.1	1863.8	2038.4	2213.0	2387.6	2562.2	0
41								1410.3	1594.1	1777.9	1961.7	2145.6	2329.4	2513.2	2697.0	0
42								1482.5	1675.7	1868.9	2062.2	2255.4	2448.6	2641.9	2835.1	0
43								1556.4	1759.3	1962.2	2165.0	2367.9	2570.8	2773.7	2976.6	0
44								1632.1	1844.8	2057.6	2270.4	2483.1	2695.9	2908.6	3121.4	1
45									1933.4	2155.3	2378.1	2601.0	2823.9	3046.7	3269.6	0
46									2021.9	2255.1	2488.3	2721.5	2954.7	3187.9	3421.1	0
47									2113.5	2357.2	2601.0	2844.8	3088.5	3332.3	3576.1	0
48									2207.0	2461.5	2716.1	2970.7	3225.2	3479.8	3734.4	0
49									2302.5	2568.1	2833.7	3099.2	3364.8	3630.4	3896.0	0
50									2400.0	2676.8	2953.7	3230.5	3507.4	3784.2	4061.1	0
BASIS TREES	0	0	1	2	3	6	11	4	5	3	4	0	0	1	0	

WHITE FIR
LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.7	1.2	1.7	2.1	2.6	3.0	3.3									1
8	1.8	3.5	5.1	6.6	8.0	9.2	10.4	11.6								1
9	3.1	6.4	9.5	12.3	14.9	17.3	19.5	21.8	24.1							2
10		9.7	14.5	18.9	23.0	26.7	30.3	33.8	37.3							2
11		13.4	20.2	26.4	32.1	37.4	42.4	47.3	52.2	57.4						2
12		17.5	26.5	34.7	42.2	49.2	55.7	62.2	68.8	75.4						1
13		21.9	33.3	43.8	53.3	62.0	70.3	78.4	86.7	95.0	103.6					1
14		26.7	40.7	53.6	65.2	75.9	86.0	95.9	105.9	116.1	126.5					1
15			48.6	64.1	78.0	90.8	102.8	114.6	126.5	138.9	150.8	163.2				2
16			57.1	75.3	91.7	106.6	120.7	134.5	148.3	162.3	176.5	190.9				1
17			66.2	87.2	106.2	123.5	139.7	155.5	171.3	187.3	203.5	219.9	236.3			2
18			75.7	99.9	121.6	141.2	159.6	177.5	195.4	213.5	231.7	250.1	268.5			2
19			85.9	113.2	137.8	159.9	180.6	200.5	220.6	240.7	261.0	281.4	301.7	321.9		1
20				127.3	154.8	179.5	202.5	224.7	246.8	269.0	291.3	313.6	335.8	357.8		1
21				142.0	172.6	200.1	225.4	249.8	274.9	298.1	322.4	346.6	370.6	394.3	417.5	1
22				157.4	191.2	221.4	249.2	275.8	301.9	328.1	354.2	380.2	405.9	431.1	455.6	2
23				173.5	210.7	243.6	273.8	302.5	331.7	358.8	386.7	414.3	441.4	467.9	493.4	1
24				190.3	230.9	266.7	299.3	330.1	361.3	391.3	419.9	448.6	476.9	504.8	530.6	3
25					251.8	290.5	325.5	358.4	391.3	423.7	452.6	480.8	508.1	534.1	566.7	2
26					273.5	315.1	352.4	387.3	422.8	453.6	484.7	516.8	546.6	574.9	601.2	1
27					295.9	340.5	380.1	416.7	451.7	485.7	519.6	553.3	586.7	616.1	643.6	2
28					319.1	366.5	408.3	446.6	483.8	517.7	551.1	585.8	619.3	652.3	683.3	2
29					342.9	393.2	437.1	476.8	516.9	549.4	583.8	618.1	652.5	687.4	689.4	2
30						420.5	466.3	507.3	545.9	580.6	613.4	643.8	678.5	694.1	711.7	1
31						448.4	496.0	538.0	576.1	611.1	643.1	671.4	699.5	714.6	728.1	1
32						476.9	526.3	568.6	606.5	640.7	670.8	696.6	717.1	731.3	738.6	2
33						505.8	556.3	599.1	636.4	668.7	696.5	718.6	734.1	74 . .	741.9	1
34						535.2	586.7	629.3	665.3	695.5	714.7	737.	746.4	746.7	736.6	2
35							617.1	659.1	693.2	720.2	733.9	751.1	750.3	743.7	7 1.	1
36							647.5	688.3	719.7	740.5	753.4	760.1	752.1	731.8	694.3	1
37							677.7	714.6	744.5	760.2	768.8	763.2	746.6	712.8	643.3	2
38							707.6	744.0	767.3	778.3	776.3	759.6	734.9	687.8	597.6	2
39							737.1	770.2	787.7	790.8	778.2	748.1	697.6	651.8	543.5	2
40								794.6	805.4	799.3	773.9	727.7	657.1	608.9	478.7	2
41								817.4	820.0	802.1	760.1	697.1	607.3	555.	411.	1
42								838.1	831.9	799.6	740.1	654.8	548.1	471.5	10 .5	2
43								856.5	837.4	790.6	710.6	594.4	445.1	343.5	5. .	2
44								872.1	839.7	774.2	672.4	528.7	336.6	88.	16.	1
45									836.4	749.6	623.1	441.1	215.	5.	16.8	2
46									827.1	715.2	554.1	334.5	97.	6.9	17.5	2
47									811.0	671.4	472.8	238.	40.8	18.	18.4	2
48									787.3	615.1	374.2	67.	48.7	19.4	19.1	2
49									755.1	545.7	256.1	70.1	46.6	.6	.	2
50									713.4	461.4	116.2	28.3	48.6	21.9	.8	2
BASIS TREES	2	3	1	2	5	5	10	1		3	4	1				

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNFORKED TREES
WHITE FIR
LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.4	.7	1.0	1.3	1.6	2.0	2.3									0
8	1.2	2.3	3.5	4.6	5.8	7.0	8.1	9.3								2
9	2.2	4.6	7.0	9.4	11.8	14.2	16.7	19.1	21.5							1
10		7.4	11.4	15.4	19.4	23.4	27.4	31.4	35.4							2
11		10.7	16.6	22.5	28.4	34.3	40.2	46.1	52.0	57.9						1
12		14.5	22.5	30.6	38.7	46.7	54.8	62.9	70.9	79.0						1
13		18.6	29.1	39.6	50.1	60.6	71.1	81.7	92.2	102.7	113.2					5
14		23.2	36.4	49.6	62.8	76.0	89.2	102.4	115.6	128.8	142.0					1
15			44.3	60.4	76.6	92.7	108.8	125.0	141.1	157.2	173.4	189.5				0
16			52.8	72.1	91.5	110.8	130.1	149.4	168.7	188.1	207.4	226.7				1
17			62.0	84.7	107.5	130.2	152.9	175.7	198.4	221.2	243.9	266.6	289.4			0
18			71.8	98.2	124.6	151.0	177.4	203.8	230.1	256.5	282.9	309.3	335.7			1
19			82.2	112.5	142.8	173.0	203.3	233.6	263.9	294.2	324.5	354.8	385.0	415.3		0
20				127.6	162.0	196.4	230.9	265.3	299.7	334.1	368.5	402.9	437.3	471.7		1
21				143.6	182.4	221.2	259.9	298.7	337.5	376.2	415.0	453.8	492.5	531.3	570.1	1
22				160.5	203.8	247.2	290.5	333.9	377.3	420.6	464.0	507.3	550.7	594.0	637.4	1
23				178.1	226.3	274.5	322.7	370.9	419.0	467.2	515.4	563.6	611.8	660.0	708.1	0
24				196.7	249.9	303.1	356.4	409.6	462.8	516.1	569.3	622.5	675.8	729.0	782.2	3
25					274.6	333.1	391.6	450.1	508.6	567.2	625.7	684.2	742.7	801.2	859.7	2
26					300.3	364.3	428.4	492.4	556.4	620.5	684.5	748.5	812.6	876.6	940.6	1
27					327.1	396.9	466.7	536.4	606.2	676.0	745.8	815.5	885.3	955.1	1024.9	0
28					355.0	430.7	506.5	582.2	658.0	733.7	809.5	885.3	961.0	1036.8	1112.5	3
29					383.9	465.9	547.8	629.8	711.8	793.7	875.7	957.6	1039.6	1121.6	1203.5	2
30						502.3	590.7	679.1	767.5	855.9	944.3	1032.7	1121.1	1209.5	1297.9	1
31						540.1	635.1	730.2	825.3	920.3	1015.4	1110.5	1205.5	1300.6	1395.7	1
32						579.1	681.1	783.1	885.0	987.0	1088.9	1190.9	1292.9	1394.8	1496.8	0
33						619.5	728.6	837.7	946.8	1055.8	1164.9	1274.0	1383.1	1492.2	1601.3	2
34						661.2	777.6	894.0	1010.5	1126.9	1243.4	1359.8	1476.3	1592.7	1709.1	2
35							828.1	952.2	1076.2	1200.2	1324.3	1448.3	1572.3	1696.4	1820.4	1
36							880.2	1012.1	1143.9	1275.8	1407.6	1539.5	1671.3	1803.1	1935.0	1
37							933.8	1073.7	1213.6	1353.5	1493.4	1633.3	1773.2	1913.1	2053.0	0
38							989.0	1137.1	1285.3	1433.5	1581.6	1729.8	1878.0	2026.1	2174.3	0
39							1045.6	1202.3	1359.0	1515.7	1672.3	1829.0	1985.7	2142.4	2299.0	0
40								1269.2	1434.7	1600.1	1765.5	1930.9	2096.3	2261.7	2427.1	0
41								1337.9	1512.3	1686.7	1861.1	2035.4	2209.8	2384.2	2558.6	0
42								1408.4	1592.0	1775.5	1959.1	2142.7	2326.3	2509.8	2693.4	0
43								1480.6	1673.6	1866.6	2059.6	2252.6	2445.6	2638.6	2831.6	0
44								1554.6	1757.2	1959.9	2162.6	2365.2	2567.9	2770.5	2973.2	1
45									1842.9	2055.4	2267.9	2480.5	2693.0	2905.6	3118.1	0
46									1930.5	2153.1	2375.8	2598.4	2821.1	3043.8	3266.4	0
47									2020.1	2253.1	2486.1	2719.1	2952.1	3185.1	3418.1	0
48									2111.7	2355.2	2598.8	2842.4	3086.0	3329.6	3573.1	0
49									2205.3	2459.6	2714.0	2968.4	3222.8	3477.2	3731.5	0
50									2300.8	2566.2	2831.7	3097.1	3362.5	3627.9	3893.3	0
BASIS TREES																

LINCOLN N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.4	.6	.9	1.2	1.4	1.6	1.8									2
8	1.1	2.2	3.2	4.0	4.8	5.6	6.2	6.9								1
9	2.1	4.3	6.3	8.2	9.8	11.3	12.7	14.1	15.6							2
10		6.9	10.3	13.4	15.1	18.6	20.9	23.2	25.6							2
11		10.0	15.0	19.5	23.6	27.2	30.6	34.0	37.4	40.9						1
12		13.5	20.4	26.6	32.1	37.0	41.7	46.2	50.9	55.7						1
13		17.4	26.3	34.4	41.5	47.9	54.0	59.9	65.8	72.0	78.3					2
14		21.6	32.9	43.0	51.9	60.0	67.4	74.8	80.2	89.8	97.6					1
15			40.0	52.3	63.2	73.0	82.1	90.9	99.9	109.0	118.4	127.8				2
16			47.7	62.4	75.4	87.0	97.8	108.2	118.8	129.5	140.5	151.6				1
17			55.9	73.2	88.5	102.0	114.5	126.7	138.9	151.3	163.9	176.7	189.6			2
18			64.7	84.8	102.4	118.0	132.3	146.2	160.1	174.2	188.5	203.0	217.5			2
19			74.1	97.0	117.1	134.8	151.1	166.7	182.3	198.1	214.1	230.3	246.4	262.5		1
20				110.0	132.7	152.6	170.8	188.2	205.5	223.0	240.7	258.5	276.2	293.7		2
21				123.6	149.0	171.2	191.4	210.6	229.6	248.7	268.0	287.4	306.5	325.4	343.9	1
22				137.9	166.2	190.7	212.9	233.8	254.5	275.2	296.1	316.8	337.3	357.4	376.9	2
23				152.9	184.1	211.0	235.1	257.9	280.1	302.4	324.6	346.6	368.2	389.3	409.5	1
24				168.6	202.7	232.1	258.2	282.6	306.4	330.0	353.4	376.5	399.1	420.9	441.5	2
25					222.2	254.0	282.0	308.0	333.2	358.0	382.5	406.4	429.6	451.6	472.4	1
26					242.3	276.6	306.5	334.0	360.4	386.2	411.4	435.9	459.3	481.3	501.6	1
27					263.2	299.9	331.6	360.5	387.9	414.4	440.2	464.8	488.1	509.9	528.7	2
28					284.7	323.8	357.3	387.4	415.6	442.6	468.4	492.8	515.3	535.5	552.0	2
29					306.9	348.4	383.5	414.5	443.2	470.4	495.2	519.3	540.8	559.1	574.1	2
30						373.6	410.1	441.9	470.8	497.6	522.4	544.5	563.4	579.4	594.7	2
31						399.3	437.1	469.3	498.1	524.1	547.4	567.6	584.0	595.8	610.5	1
32						425.6	464.4	496.7	524.8	549.5	570.8	590.6	607.6	618.2	628.9	2
33						452.3	491.8	523.9	550.9	573.6	593.1	612.3	629.2	640.6	647.1	2
34						479.3	519.4	550.8	576.1	596.1	616.8	634.4	650.8	662.7	667.7	2
35							547.0	577.2	600.1	616.7	636.6	654.1	670.1	680.5	678.8	1
36							574.4	603.0	622.8	634.8	653.9	673.8	689.2	698.4	688.9	1
37							601.7	627.9	643.7	650.3	667.1	687.9	705.3	716.3	698.3	2
38							628.6	651.7	664.7	666.5	680.6	699.4	685.0	727.1	707.5	2
39							655.1	674.3	679.3	671.1	688.7	710.5	734.0	736.5	715.7	2
40								695.4	694.3	675.4	690.7	687.1	711.6	721.1	698.1	2
41								714.7	704.1	674.9	686.4	654.0	686.3	698.8	667.3	1
42								733.0	711.4	669.3	672.9	610.0	647.1	657.1	617.5	2
43								746.9	714.7	656.8	644.1	554.6	593.6	594.5	547.5	2
44								759.1	713.5	637.7	599.2	483.2	524.1	514.5	463.1	1
45									707.1	610.8	545.9	397.1	437.3	414.5	363.1	2
46									695.0	575.0	476.2	303.3	333.2	294.5	247.1	2
47									676.4	529.4	387.8	199.5	211.9	156.9	117.6	2
48									650.6	470.9	283.5	84.5	80.8	28.1	16.1	2
49									616.3	404.0	159.8	67.4	44.7	29.1	19.1	2
50									574.2	321.4	104.3	50.3	40.6	31.6	19.9	2
BASIC TREES	0	0	1	2	3	5	12	5	3	3	3	1	1	1	1	

TOTAL STEM GROSS CUBIC FOOT VOLUME-UNBROKEN TREES
WHITE FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
1	.2															0
2	.2	.3														1
3	.3	.5	.7													0
4	.5	.8	1.1	1.4												0
5	.7	1.2	1.7	2.2	2.7											7
6	.9	1.6	2.3	3.1	3.8	4.5										4
7	1.1	2.1	3.1	4.1	5.1	6.1	7.0									7
8	1.4	2.7	4.0	5.3	6.6	7.9	9.2	10.4								7
9	1.8	3.4	5.0	6.7	8.3	9.9	11.5	13.2	14.8							3
10		4.2	6.2	8.2	10.2	12.2	14.2	16.2	18.2							2
11		5.0	7.5	9.9	12.3	14.7	17.2	19.6	22.0	24.5						1
12		5.9	8.8	11.7	14.6	17.5	20.4	23.3	26.2	29.1						2
13		6.9	10.3	13.7	17.1	20.5	23.9	27.3	30.7	34.1	37.5					4
14		8.0	12.0	15.9	19.8	23.8	27.7	31.7	35.6	39.5	43.5					3
15			13.7	18.2	22.8	27.3	31.8	36.3	40.8	45.4	49.9	54.4				1
16			15.6	20.7	25.9	31.0	36.2	41.3	46.4	51.6	56.7	61.9				4
17			17.6	23.4	29.2	35.0	40.8	46.6	52.4	58.2	64.0	69.8	75.6			1
18			19.7	26.2	32.7	39.2	45.7	52.2	58.7	65.3	71.8	78.3	84.8			1
19			21.9	29.2	36.4	43.7	50.9	58.2	65.4	72.7	79.9	87.2	94.4	101.7		0
20				32.3	40.3	48.4	56.4	64.4	72.5	80.5	88.6	96.6	104.6	112.7		0
21				35.6	44.5	53.3	62.2	71.0	79.9	88.8	97.6	106.5	115.3	124.2	133.1	0
22				39.1	48.8	58.5	68.2	78.0	87.7	97.4	107.1	116.8	126.6	136.3	146.0	2
23				42.7	53.3	63.9	74.6	85.2	95.8	106.4	117.1	127.7	138.3	149.0	159.6	0
24				46.4	58.0	69.6	81.2	92.7	104.3	115.9	127.5	139.0	150.6	162.2	173.7	0
25					62.9	75.5	88.1	100.6	113.2	125.7	138.3	150.8	163.4	176.0	188.5	1
26					68.1	81.6	95.2	108.8	122.4	136.0	149.6	163.1	176.7	190.3	203.9	0
27					73.4	88.0	102.7	117.3	132.0	146.6	161.3	175.9	190.6	205.2	219.9	0
28					78.9	94.7	110.4	126.2	141.9	157.7	173.4	189.2	204.9	220.7	236.4	1
29					84.6	101.5	118.4	135.3	152.2	169.1	186.0	202.9	219.8	236.7	253.6	0
30						108.7	126.7	144.8	162.9	181.0	199.1	217.1	235.2	253.3	271.4	0
31						116.0	135.3	154.6	173.9	193.2	212.5	231.8	251.2	270.5	289.8	0
32						123.6	144.2	164.7	185.3	205.9	226.5	247.0	267.6	288.2	308.8	0
33						131.4	153.3	175.2	197.1	219.0	240.8	262.7	284.6	306.5	328.3	0
34						139.5	162.7	186.0	209.2	232.4	255.6	278.9	302.1	325.3	348.5	0
35							172.4	197.1	221.7	246.3	270.9	295.5	320.1	344.7	369.3	0
36							182.4	208.5	234.5	260.5	286.6	312.6	338.7	364.7	390.7	0
37							192.7	220.2	247.7	275.2	302.7	330.2	357.7	385.2	412.7	0
38							203.2	232.3	261.3	290.3	319.3	348.3	377.3	406.3	435.3	0
39							214.1	244.6	275.2	305.7	336.3	366.9	397.4	428.0	458.5	0
40								257.3	289.5	321.6	353.8	385.9	418.1	450.2	482.3	0
41								270.3	304.1	337.9	371.7	405.4	439.2	473.0	506.8	0
42								283.7	319.1	354.6	390.0	425.4	460.9	496.3	531.8	0
43								297.3	334.5	371.6	408.8	445.9	483.1	520.2	557.4	0
44								311.3	350.2	389.1	428.0	466.9	505.8	544.7	583.6	0
45									366.3	407.0	447.7	488.4	529.1	569.7	610.4	0
46									382.8	425.3	467.8	510.3	552.8	595.3	637.9	0
47									399.6	444.0	488.4	532.7	577.1	621.5	665.9	0
48									416.8	463.1	509.3	555.6	601.9	648.2	694.5	0
49									434.3	482.5	530.8	579.0	627.3	675.5	723.7	0
50									452.2	502.4	552.7	602.9	653.1	703.4	753.6	0

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREE
1	.2															0
2	.2	.3														0
3	.3	.5	.7													1
4	.5	.8	1.1	1.4												1
5	.7	1.2	1.7	2.2	2.7											1
6	.9	1.6	2.3	3.0	3.8	4.5										4
7	1.1	2.1	3.1	4.1	5.0	6.0	7.0									7
8	1.4	2.7	4.0	5.3	6.5	7.8	9.0	10.2								7
9	1.8	3.4	5.0	6.6	8.2	9.8	11.3	12.8	14.3							4
10		4.2	6.1	8.1	10.0	12.0	13.8	15.7	17.6							3
11		5.0	7.4	9.7	12.1	14.4	16.6	18.8	21.0	23.3						
12		5.9	8.7	11.5	14.3	17.0	19.6	22.2	24.8	27.4						2
13		6.9	10.2	13.5	16.7	19.8	22.9	25.9	28.8	31.8	34.8					4
14		8.0	11.8	15.6	19.3	22.9	26.3	29.7	33.1	36.5	39.9					3
15			13.5	17.8	22.0	26.1	30.0	33.8	37.6	41.4	45.3	49.1				1
16			15.3	20.2	24.9	29.5	33.9	38.2	42.4	46.6	50.9	55.2				4
17			17.2	22.7	28.0	33.1	38.0	42.7	47.3	52.0	56.7	61.4	66.3			2
18			19.3	25.4	31.2	36.9	42.3	47.4	52.5	57.6	62.7	67.9	73.3			1
19			21.4	28.2	34.6	40.8	46.7	52.3	57.8	63.3	68.9	74.6	80.4	86.3		2
20				31.1	38.2	44.9	51.3	57.4	63.3	69.3	75.3	81.5	87.8	94.2		2
21				34.2	41.9	49.2	56.1	62.6	69.0	75.4	81.9	88.6	95.3	102.3	109.3	1
22				37.4	45.8	53.7	61.1	68.1	74.9	81.7	88.6	95.8	103.2	111.5	118.1	2
23				40.7	49.8	58.3	66.3	73.7	80.9	88.1	95.5	103.1	110.9	118.9	127.1	1
24				44.2	54.0	63.1	71.5	79.4	87.1	94.9	102.8	110.8	118.9	127.4	136.1	
25					58.3	68.1	77.0	85.3	93.4	101.5	109.7	118.1	126.7	135.7	144.9	
26					62.8	73.2	82.6	91.4	99.9	108.3	117.0	125.7	134.7	143.9	153.4	
27					67.4	78.5	88.4	97.6	106.5	115.4	124.5	133.7	143.2	152.8	162.9	
28					72.2	83.9	94.4	104.0	113.3	122.5	132.1	141.8	151.8	162.1	172.8	
29					77.2	89.5	100.5	110.6	120.3	129.8	139.8	150.1	161.0	171.7	183.0	
30						95.3	106.8	117.3	127.3	137.3	147.7	158.5	169.8	181.5	193.6	
31						101.2	113.3	124.2	134.6	144.7	155.7	167.1	178.8	191.1		
32						107.3	119.9	131.3	142.2	152.7	164.0	175.6	187.9	200.8		
33						113.6	126.7	138.8	149.6	160.6	172.6	184.6	197.3	211.6	224.6	
34						120.0	133.7	146.9	157.3	168.8	181.7	194.4	206.8	222.7	235.1	
35							141.9	155.5	165.3	177.1	189.4	203.6	216.4	234.4		
36							148.1	161.7	173.4	185.4	198.3	211.9	226.3	241.4		
37							155.8	169.3	181.7	194.1	207.4	221.5	236.4	251.5		
38							163.5	177.4	190.3	203.1	216.7	231.4	246.8	263.1	280.0	
39							171.4	185.8	199.0	212.3	226.4	241.6	257.4	274.8	291.9	
40								194.3	207.9	221.6	236.2	251.5	268.2	285.7		
41								203.1	217.0	231.1	246.2	261.5	279.2	297.5		
42								212.1	226.3	241.0	256.4	272.8	290.4	309.5		
43								221.4	236.0	251.1	266.8	284.4	302.8	322.7		
44								230.8	246.0	261.3	277.5	296.2	315.4	336.2		
45									256.3	272.0	288.5	308.2	328.2	350.0		
46									266.5	282.9	300.0	320.4	341.3	364.0		
47									277.0	293.8	311.7	333.0	354.7	378.2		
48									288.1	305.1	323.7	345.9	368.5	392.8		
49									299.7	316.8	335.9	358.9	382.6	407.8		
50									310.6	328.7	348.5	372.3	396.9	423.0		
BASIC TREE	0	1	15	15	12	8	7									

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 4 INCHES-UNFORKED TREES
WHITE FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.3	.5	.6	.8	.9											7
6	.6	1.0	1.5	1.9	2.4	2.8										4
7	.8	1.6	2.3	3.1	3.9	4.6	5.4									7
8	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8								7
9	1.3	2.8	4.3	5.8	7.2	8.7	10.2	11.7	13.2							3
10		3.5	5.4	7.3	9.1	11.0	12.9	14.8	16.7							2
11		4.3	6.6	8.9	11.2	13.5	15.9	18.2	20.5	22.8						1
12		5.1	7.9	10.7	13.5	16.2	19.0	21.8	24.6	27.4						2
13		5.9	9.3	12.6	15.9	19.2	22.5	25.8	29.1	32.4	35.7					4
14		6.9	10.7	14.6	18.5	22.3	26.2	30.0	33.9	37.8	41.6					3
15			12.3	16.8	21.2	25.7	30.1	34.6	39.0	43.5	47.9	52.4				1
16			14.0	19.1	24.2	29.3	34.4	39.4	44.5	49.6	54.7	59.8				4
17			15.8	21.6	27.3	33.1	38.8	44.6	50.3	56.1	61.8	67.6	73.3			1
18			17.8	24.2	30.7	37.1	43.6	50.0	56.5	63.0	69.4	75.9	82.3			1
19			19.8	27.0	34.2	41.4	48.6	55.8	63.0	70.2	77.4	84.6	91.8	99.0		0
20				29.9	37.9	45.9	53.9	61.9	69.8	77.8	85.8	93.8	101.8	109.8		0
21				33.0	41.8	50.6	59.4	68.2	77.0	85.9	94.7	103.5	112.3	121.1	130.0	0
22				36.2	45.8	55.5	65.2	74.9	84.6	94.3	104.0	113.6	123.3	133.0	142.7	2
23				39.5	50.1	60.7	71.3	81.9	92.5	103.1	113.7	124.2	134.8	145.4	156.0	0
24				43.0	54.6	66.1	77.6	89.2	100.7	112.2	123.8	135.3	146.9	158.4	169.9	0
25					59.2	71.7	84.2	96.8	109.3	121.8	134.3	146.9	159.4	171.9	184.4	1
26					64.0	77.6	91.1	104.7	118.2	131.8	145.3	158.9	172.4	186.0	199.5	0
27					69.0	83.6	98.3	112.9	127.5	142.1	156.7	171.4	186.0	200.6	215.2	0
28					74.2	90.0	105.7	121.4	137.1	152.9	168.6	184.3	200.0	215.7	231.5	1
29					79.6	96.5	113.4	130.2	147.1	164.0	180.8	197.7	214.6	231.5	248.3	0
30						103.3	121.3	139.4	157.4	175.5	193.5	211.6	229.7	247.7	265.8	0
31						110.2	129.5	148.8	168.1	187.4	206.7	226.0	245.2	264.5	283.8	0
32						117.5	138.0	158.6	179.1	199.7	220.2	240.8	261.3	281.9	302.4	0
33						124.9	146.8	168.6	190.5	212.3	234.2	256.1	277.9	299.8	321.6	0
34						132.6	155.8	179.0	202.2	225.4	248.6	271.8	295.0	318.2	341.4	0
35							165.1	189.7	214.3	238.9	263.5	288.1	312.6	337.2	361.8	0
36							174.7	200.7	226.7	252.7	278.7	304.7	330.8	356.8	382.8	0
37							184.5	212.0	239.5	266.9	294.4	321.9	349.4	376.9	404.4	0
38							194.6	223.6	252.6	281.6	310.6	339.6	368.5	397.5	426.5	0
39							205.0	235.5	266.0	296.6	327.1	357.7	388.2	418.7	449.3	0
40								247.7	279.8	312.0	344.1	376.2	408.4	440.5	472.6	0
41								260.3	294.0	327.8	361.5	395.3	429.0	462.8	496.6	0
42								273.1	308.5	343.9	379.4	414.8	450.2	485.7	521.1	0
43								286.2	323.4	360.5	397.7	434.8	471.9	509.1	546.2	0
44								299.7	338.6	377.5	416.4	455.2	494.1	533.0	571.9	0
45									354.2	394.8	435.5	476.2	516.8	557.5	598.2	0
46									370.1	412.6	455.1	497.6	540.1	582.6	625.1	0
47									386.3	430.7	475.1	519.4	563.8	608.2	652.5	0
48									402.9	449.2	495.5	541.8	588.0	634.3	680.6	0
49									419.9	468.1	516.3	564.6	612.8	661.0	709.2	0
50									437.2	487.4	537.6	587.8	638.1	688.3	738.5	0
BASIS																

WHITE FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
5	.3	.5	.6	.8	.9											
6	.6	1.0	1.5	1.9	2.4	2.8										4
7	.8	1.6	2.3	3.1	3.8	4.6	5.3									7
8	1.1	2.2	3.3	4.4	5.4	6.5	7.6	8.6								7
9	1.3	2.8	4.3	5.7	7.1	8.6	10.0	11.4	12.7							4
10		3.5	5.3	7.2	9.0	10.8	12.6	14.3	16.0							3
11		4.2	6.5	8.8	11.0	13.2	15.3	17.5	19.6	21.7						-
12		5.0	7.8	10.5	13.2	15.8	18.3	20.8	23.3	25.8						2
13		5.9	9.1	12.3	15.5	18.5	21.5	24.4	27.3	30.2	33.2					4
14		6.8	10.6	14.3	17.9	21.5	24.9	28.2	31.6	34.9	38.2					2
15			12.1	16.4	20.5	24.6	28.4	32.2	36.0	39.7	43.5	47.3				1
16			13.8	18.6	23.3	27.8	32.2	36.4	40.6	44.8	49.0	53.3				4
17			15.5	21.0	26.2	31.3	36.1	40.8	45.5	50.1	54.7	59.5	64.3			2
18			17.4	23.4	29.3	34.9	40.2	45.4	50.5	55.5	60.7	65.9	71.2			1
19			19.3	26.0	32.5	38.7	44.5	50.2	55.7	61.2	66.8	72.5	78.2	84.1		0
20				28.8	35.9	42.6	49.0	55.1	61.0	67.0	73.0	79.2	85.5	91.9		-
21				31.6	39.4	46.7	53.6	60.2	66.6	73.0	79.5	86.1	92.9	99.8	106.8	1
22				34.6	43.0	51.0	58.4	65.4	72.2	79.1	86.1	93.2	100.5	107.9	115.4	2
23				37.7	46.8	55.4	63.3	70.8	78.1	85.4	92.8	100.4	108.2	116.1	124.2	1
24				40.9	50.8	60.0	68.4	76.4	84.1	91.8	99.7	107.7	116.0	124.5	133.2	0
25					54.9	64.7	73.7	82.1	90.2	98.4	106.7	115.2	124.0	133.1	142.3	1
26					59.1	69.5	79.1	88.0	96.5	105.1	113.8	122.8	132.2	141.7	151.5	0
27					63.5	74.6	84.7	94.0	103.0	111.9	121.1	130.6	140.4	150.5	160.8	-
28					68.0	79.8	90.4	100.2	109.5	118.9	128.5	138.5	148.8	159.5	170.3	1
29					72.6	85.1	96.3	106.5	116.3	126.0	136.0	146.5	157.3	168.5	180.0	0
30						90.6	102.3	113.0	123.1	133.3	143.7	154.6	166.0	177.7	189.8	0
31						96.2	108.5	119.6	130.2	140.7	151.6	162.9	174.8	187.1	199.8	-
32						102.0	114.9	126.4	137.4	148.3	159.5	171.4	183.8	196.6	209.9	-
33						108.0	121.4	133.4	144.7	156.0	167.7	180.1	192.9	206.3	220.2	0
34						114.1	128.1	140.6	152.2	163.9	175.9	188.8	202.2	216.2	230.7	0
35							135.0	147.9	159.9	172.0	184.5	197.7	211.7	226.3	241.4	0
36							142.0	155.4	167.8	180.2	193.2	206.9	221.4	236.6	252.3	-
37							149.3	163.1	175.9	188.7	202.2	216.3	231.3	247.1	263.5	1
38							156.7	170.9	184.1	197.3	211.1	225.8	241.6	257.9	274.9	0
39							164.3	179.0	192.6	206.2	220.4	235.7	251.8	268.9	286.5	-
40								187.3	201.3	215.3	230.0	245.7	262.3	280.1	298.4	0
41								195.8	210.2	224.6	239.7	256.0	273.4	292.1	312.0	-
42								204.5	219.3	234.1	249.7	266.5	284.5	303.5	324.0	-
43								213.4	228.6	243.9	260.0	277.3	296.1	315.6	336.7	-
44								222.5	238.2	253.9	270.5	288.4	307.7	328.1	349.8	-
45									248.0	264.2	281.3	299.8	319.7	340.9	363.9	0
46									258.1	274.7	292.3	311.5	332.1	354.1	378.0	-
47									268.4	285.5	303.7	323.4	344.8	367.4	391.3	-
48									278.9	296.6	315.3	335.7	357.8	381.1	406.0	-
49									289.8	307.9	327.2	348.2	371.1	395.1	421.0	-
50									300.8	319.5	339.4	361.0	384.7	409.8	436.3	-
BASIS TREES	0	7	15	15	12	6	3	7	1	3	1	1	1	1	1	

GROSS CUBIC FOOT VOLUME TO TOP DIB OF 6 INCHES -UNFORKED TREES
WHITE FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIC TREES
7	.3	.5	.8	1.0	1.3	1.5	1.8									6
8	.6	1.3	2.0	2.7	3.4	4.1	4.7	5.4								7
9	1.0	2.1	3.2	4.3	5.5	6.6	7.7	8.8	9.9							3
10		2.9	4.5	6.0	7.6	9.2	10.8	12.4	13.9							2
11		3.7	5.8	7.8	9.9	12.0	14.0	16.1	18.1	20.2						4
12		4.6	7.2	9.7	12.3	14.9	17.4	20.0	22.6	25.1						2
13		5.5	8.6	11.7	14.8	17.9	21.1	24.2	27.3	30.4	33.5					4
14		6.5	10.2	13.9	17.5	21.2	24.9	28.6	32.3	35.9	39.6					3
15			11.8	16.1	20.4	24.7	29.0	33.3	37.6	41.8	46.1	50.4				1
16			13.6	18.5	23.4	28.4	33.3	38.2	43.2	48.1	53.0	58.0				4
17			15.4	21.0	26.7	32.3	37.9	43.5	49.1	54.7	60.3	65.9	71.5			1
18			17.4	23.7	30.0	36.4	42.7	49.0	55.4	61.7	68.0	74.4	80.7			1
19			19.4	26.5	33.6	40.7	47.8	54.9	62.0	69.0	76.1	83.2	90.3	97.4		0
20				29.5	37.3	45.2	53.1	61.0	68.9	76.8	84.6	92.5	100.4	108.3		0
21				32.6	41.3	50.0	58.7	67.4	76.1	84.9	93.6	102.3	111.0	119.7	128.5	2
22				35.8	45.4	55.0	64.6	74.2	83.7	93.3	102.9	112.5	122.1	131.7	141.3	2
23				39.2	49.7	60.2	70.7	81.2	91.7	102.2	112.7	123.2	133.7	144.2	154.7	0
24				42.7	54.1	65.6	77.1	88.5	100.0	111.4	122.9	134.3	145.8	157.3	168.7	0
25					58.8	71.3	83.7	96.2	108.6	121.0	133.5	145.9	158.4	170.8	183.3	1
26					63.7	77.1	90.6	104.1	117.6	131.0	144.5	158.0	171.5	185.0	198.4	0
27					68.7	83.2	97.8	112.3	126.9	141.4	156.0	170.5	185.1	199.6	214.2	0
28					73.9	89.6	105.2	120.9	136.5	152.2	167.9	183.5	199.2	214.8	230.5	1
29					79.3	96.1	112.9	129.7	146.5	163.4	180.2	197.0	213.8	230.6	247.4	0
30						102.9	120.9	138.9	156.9	174.9	192.9	210.9	228.9	246.9	264.9	0
31						109.9	129.1	148.4	167.6	186.8	206.1	225.3	244.5	263.7	283.0	0
32						117.1	137.6	158.1	178.6	199.1	219.6	240.1	260.6	281.1	301.6	0
33						124.6	146.4	168.2	190.0	211.8	233.6	255.5	277.3	299.1	320.9	0
34						132.3	155.5	178.6	201.8	224.9	248.1	271.2	294.4	317.6	340.7	0
35							164.8	189.3	213.9	238.4	262.9	287.5	312.0	336.6	361.1	0
36							174.3	200.3	226.3	252.3	278.2	304.2	330.2	356.2	382.1	0
37							184.2	211.6	239.1	266.5	294.0	321.4	348.8	376.3	403.7	0
38							194.3	223.2	252.2	281.2	310.1	339.1	368.0	397.0	425.9	0
39							204.7	235.2	265.7	296.2	326.7	357.2	387.7	418.2	448.7	0
40								247.4	279.5	311.6	343.7	375.8	407.9	440.0	472.1	0
41								260.0	293.7	327.4	361.1	394.8	428.6	462.3	496.0	0
42								272.8	308.2	343.6	379.0	414.4	449.8	485.2	520.5	0
43								286.0	323.1	360.2	397.3	434.4	471.5	508.6	545.7	0
44								299.4	338.3	377.1	416.0	454.8	493.7	532.5	571.4	0
45									353.9	394.5	435.1	475.8	516.4	557.1	597.7	0
46									369.8	412.3	454.7	497.2	539.7	582.1	624.6	0
47									386.1	430.4	474.7	519.1	563.4	607.7	652.1	0
48									402.7	448.9	495.2	541.4	587.7	633.9	680.2	0
49									419.6	467.8	516.0	564.2	612.4	660.6	708.8	0
50									436.9	487.1	537.3	587.5	637.7	687.9	738.1	0
BASIS TREES	0	1	10	12	11	6	2	5	1	0	0	0	0	0	0	

WHITE FIR

SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIL TREE
7	.3	.5	.8	1.0	1.3	1.5	1.8									7
8	.6	1.3	2.0	2.7	3.3	4.0	4.6	5.3								7
9	1.0	2.1	3.2	4.3	5.4	6.5	7.5	8.6	9.6							4
10		2.9	4.4	6.0	7.5	9.0	10.5	12.1	13.4							1
11		3.7	5.7	7.7	9.7	11.6	13.6	15.4	17.3	19.						
12		4.6	7.1	9.6	12.0	14.4	16.8	19.1	21.4	23.7						
13		5.5	8.5	11.5	14.5	17.3	20.1	22.9	25.6	28.3	31.					1
14		6.5	10.0	13.6	17.0	20.4	23.6	26.8	30.0	33.	36.2					1
15			11.7	15.7	19.7	23.6	27.3	31.0	34.6	38.	41.8	45.5				1
16			13.3	18.0	22.6	27.0	31.1	35.3	39.4	43.	47.5	51.6				
17			15.1	20.4	25.6	30.5	35.1	39.8	44.3	48.8	53.	58.	62.			1
18			17.0	23.0	28.7	34.3	39.4	44.5	49.4	54.	59.	64.5	69.7			1
19			19.0	25.6	32.0	38.0	43.8	49.3	54.5	60.1	65.6	71.	76.3	81.6		
20				28.4	35.4	42.0	48.3	54.1	60.1	66.	72.	78.	84.	91.5		
21				31.2	38.9	46.1	52.9	59.4	65.7	72.	78.5	85.	91.7	98.5	105.	
22				34.3	42.6	51.4	57.8	64.7	71.4	78.	85.1	91.	99.4	106.	114.	
23				37.3	46.4	54.9	62.7	70.1	77.4	84.	91.	98.4	107.1	115.	123.	1
24				40.6	50.4	59.5	67.8	75.8	83.4	91.	98.8	106.8	115.0	123.5	132.	
25					54.5	64.2	73.2	81.5	89.6	97.6	105.9	114.	123.1	132.	141.	1
26					58.7	69.1	78.6	87.4	95.9	104.	113.	122.	131.	141.	151.	
27					63.1	74.3	84.3	93.5	102.3	111.	120.	129.8	139.5	149.6	159.8	
28					67.6	79.4	89.9	99.	108.9	118.	128.	137.	147.	158.5	169.	
29					72.3	84.7	95.8	106.	115.	125.	135.	145.7	156.5	167.6	179.	
30						90.2	102.0	112.	122.	132.	142.	153.	165.	176.9	188.	
31						95.9	108.1	119.	129.6	140.	151.9	162.	174.	186.	198.6	
32						101.7	114.5	125.	136.8	148.	158.9	170.	183.	195.8	209.	
33						107.7	121.	132.	144.	155.	167.	179.	192.1	205.5	219.	
34						113.8	127.	140.	151.	163.	176.	188.1	201.5	215.	229.	
35							134.6	147.	159.	172.	185.	197.	211.	225.	239.	
36							141.7	155.	167.	181.	194.	206.	221.	236.	250.	
37							148.9	163.	175.	188.	203.	215.6	232.	246.	261.	
38							156.3	171.	183.	198.	213.	225.	242.	257.	272.	
39							164.	178.	191.	206.	222.	235.	252.	268.	285.	
40								186.	200.	215.	232.	245.	263.	279.	297.	
41								195.	209.	225.	242.	255.	274.	291.	309.	
42								204.	218.	235.	252.	266.	285.	303.	321.	
43								214.	228.	245.	263.	277.	297.	315.	334.	
44								223.	238.	255.	274.	288.	309.	328.	348.	
45								233.	247.	266.	285.	300.	321.	341.	361.	
46								242.	257.	276.	296.	312.	333.	354.	375.	
47								252.	268.	287.	308.	324.	346.	367.	389.	
48								262.	278.	298.	319.	336.	359.	381.	403.	
49								272.	289.	309.	331.	348.	372.	395.	418.	
50								282.	300.	321.	343.	361.	385.	409.	433.	
BASIC TREES	2	7	10	12	11	6	3	7	1	1	1	1	1	1	1	

GROSS INTERNATIONAL BOARD FOOT VOLUME TO 6 INCH TOP DIB-ONE MARKED TREES
WHITE FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	1.2	2.2	3.1	4.1	5.1	6.1	7.0									1
8	2.8	5.8	8.7	11.7	14.7	17.6	20.6	23.6								2
9	4.5	9.7	14.9	20.1	25.3	30.4	35.6	40.8	46.0							3
10		14.0	21.5	29.1	36.7	44.3	51.9	59.5	67.1							2
11		18.5	28.7	38.9	49.1	59.3	69.5	79.7	90.0	100.2						1
12		23.4	36.4	49.4	62.4	75.4	88.4	101.5	114.5	127.5						2
13		28.6	44.6	60.6	76.6	92.7	108.7	124.7	140.7	156.8	172.8					4
14		34.1	53.3	72.6	91.8	111.1	130.3	149.5	168.8	188.0	207.3					3
15			62.6	85.3	108.0	130.7	153.3	176.0	198.7	221.3	244.0	266.7				1
16			72.5	98.8	125.2	151.5	177.8	204.1	230.4	256.7	283.0	309.3				4
17			83.0	113.2	143.3	173.5	203.7	233.9	264.0	294.2	324.4	354.5	384.7			1
18			94.0	128.3	162.5	196.8	231.0	265.3	299.6	333.8	368.1	402.3	436.6			1
19			105.7	144.2	182.8	221.3	259.9	298.4	337.0	375.5	414.1	452.7	491.2	529.8		0
20				161.0	204.1	247.1	290.2	333.3	376.4	419.4	462.5	505.6	548.7	591.8		0
21				178.6	226.4	274.2	322.0	369.9	417.7	465.5	513.3	561.2	609.0	656.8	704.6	0
22				197.0	249.8	302.6	355.4	408.2	461.0	513.7	566.5	619.3	672.1	724.9	777.7	2
23				216.2	274.2	332.2	390.2	448.2	506.2	564.2	622.2	680.2	738.1	796.1	854.1	0
24				236.3	299.7	363.1	426.5	490.0	553.4	616.8	680.2	743.6	807.0	870.4	933.9	0
25					326.3	395.3	464.4	533.5	602.5	671.6	740.7	809.7	878.8	947.9	1016.9	1
26					353.9	428.9	503.8	578.7	653.7	728.6	803.6	878.5	953.4	1028.4	1103.3	0
27					382.6	463.7	544.7	625.7	706.8	787.8	868.9	949.9	1031.0	1112.0	1193.1	0
28					412.4	499.8	587.1	674.5	761.9	849.3	936.6	1024.0	1111.4	1198.8	1286.1	1
29					443.2	537.2	631.1	725.0	819.0	912.9	1006.8	1100.8	1194.7	1288.7	1382.6	0
30						575.9	676.6	777.3	878.0	978.8	1079.5	1180.2	1280.9	1381.7	1482.4	0
31						615.9	723.6	831.4	939.1	1046.8	1154.6	1262.3	1370.1	1477.8	1585.6	0
32						657.2	772.2	887.2	1002.1	1117.1	1232.1	1347.1	1462.1	1577.1	1692.1	0
33						699.8	822.3	944.7	1067.2	1189.6	1312.1	1434.6	1557.0	1679.5	1802.0	0
34						743.7	873.9	1004.0	1134.2	1264.4	1394.6	1524.7	1654.9	1785.1	1915.3	0
35							927.0	1065.1	1203.2	1341.3	1479.5	1617.6	1755.7	1893.8	2031.9	0
36							981.7	1128.0	1274.3	1420.5	1566.8	1713.1	1859.3	2005.6	2151.9	0
37							1038.0	1192.6	1347.3	1501.9	1656.6	1811.3	1965.9	2120.6	2275.2	0
38							1095.7	1259.0	1422.3	1585.6	1748.9	1912.1	2075.4	2238.7	2402.0	0
39							1155.0	1327.2	1499.3	1671.4	1843.6	2015.7	2187.9	2360.0	2532.1	0
40								1397.1	1578.3	1759.5	1940.8	2122.0	2303.2	2484.4	2665.6	0
41								1468.8	1659.3	1849.9	2040.4	2230.9	2421.4	2612.0	2802.5	0
42								1542.3	1742.3	1942.4	2142.5	2342.6	2542.6	2742.7	2942.8	0
43								1617.5	1827.4	2037.2	2247.0	2456.9	2666.7	2876.6	3086.4	0
44								1694.5	1914.4	2134.2	2354.0	2573.9	2793.7	3013.6	3233.4	0
45									2003.4	2233.4	2463.5	2693.6	2923.7	3153.7	3383.8	0
46									2094.4	2334.9	2575.5	2816.0	3056.5	3297.1	3537.6	0
47									2187.4	2438.6	2689.9	2941.1	3192.3	3443.5	3694.8	0
48									2282.4	2544.6	2806.7	3068.9	3331.0	3593.2	3855.3	0
49									2379.4	2652.7	2926.0	3199.3	3472.6	3745.9	4019.2	0
50									2478.4	2763.1	3047.8	3332.5	3617.2	3901.9	4186.6	0
BASIS TREES	0	1	9	12	11	6	2	5	1	0	0	0	0	0	0	

WHITE FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	1.1	2.0	3.0	3.9	4.8	5.7	6.7									6
8	2.6	5.4	8.2	11.0	13.7	16.5	19.3	22.1								7
9	4.2	9.0	13.8	18.6	23.3	28.1	32.9	37.7	42.5							4
10		12.7	19.6	26.6	33.5	40.4	47.3	54.2	61.0							3
11		16.6	25.8	34.9	44.0	53.1	62.2	71.3	80.4	89.5						
12		20.6	32.1	43.6	55.0	66.4	77.8	89.1	100.4	111.7						2
13		24.8	38.7	52.5	66.3	80.0	93.8	107.4	121.1	134.7	148.2					4
14		29.1	45.4	61.7	77.9	94.1	110.2	126.3	142.3	158.2	174.0					3
15			52.4	71.2	89.9	108.6	127.1	145.6	164.0	182.2	200.4	218.5				1
16			59.6	81.0	102.3	123.5	144.5	165.4	186.2	206.8	227.3	247.6				2
17			67.1	91.2	115.1	138.8	162.4	185.8	208.9	231.9	254.7	277.3	299.7			2
18			74.9	101.7	128.3	154.7	180.8	206.7	232.3	257.6	282.7	307.4	331.9			1
19			83.0	112.7	142.0	171.1	199.8	228.2	256.2	283.9	311.2	338.1	364.6	390.8		2
20				124.0	156.2	188.1	219.4	250.4	280.8	310.8	340.3	369.3	397.7	425.7		2
21				135.8	171.0	205.6	239.7	273.2	306.0	338.2	369.9	400.9	431.3	460.7	489.6	1
22				148.1	186.3	223.8	260.6	296.6	331.9	366.4	400.1	433.0	464.8	495.8	525.9	2
23				160.9	202.0	242.6	282.1	320.7	358.4	395.2	430.6	465.1	498.5	530.7	561.7	1
24				174.2	218.7	262.0	304.3	345.5	385.4	424.1	461.4	497.4	532.0	565.1	596.7	2
25					235.7	282.1	327.1	370.7	412.8	453.4	492.4	529.7	565.2	598.8	630.5	1
26					253.2	302.6	350.4	396.4	440.7	483.9	523.4	561.6	597.6	631.4	663.7	
27					271.3	323.7	374.2	422.6	468.7	512.6	554.0	592.2	629.1	663.4	695.1	1
28					289.8	345.3	398.4	449.2	496.9	540.3	584.2	623.2	659.0	691.3	719.8	1
29					308.8	367.3	422.9	475.5	525.0	571.1	613.6	653.4	687.1	717.5	743.4	2
30						389.6	447.6	502.1	551.8	599.5	641.9	679.7	712.7	740.4	762.6	
31						412.2	472.5	528.6	580.3	627.1	668.8	704.9	735.3	759.2	776.6	
32						435.0	497.4	554.9	607.9	653.4	692.8	727.5	754.2	773.1	784.1	
33						458.0	522.2	580.7	635.8	678.3	716.5	746.8	768.7	781.4	784.3	
34						481.0	546.8	605.8	657.5	701.3	736.4	762.3	777.4	781.7	775.5	
35							571.2	630.2	680.8	722.3	753.1	772.1	781.2	775.9	754.1	
36							594.8	653.5	703.3	740.1	765.9	778.6	777.1	759.7	725.4	
37							617.8	675.6	721.7	755.3	774.2	777.9	764.7	731.7	684.4	
38							640.3	696.1	738.6	766.1	777.2	777.1	742.1	694.1	634.9	
39							661.2	714.8	753.7	773.3	774.3	753.9	709.8	639.1	539.6	
40								731.4	763.5	775.3	744.4	728.4	664.3	568.8	448.6	
41								745.6	770.4	771.8	746.7	693.1	604.1	479.4	358.1	
42								756.9	773.1	761.9	730.3	643.4	537.8	368.1	159.6	
43								765.1	770.8	744.9	694.1	580.8	462.6	231.6		7
44								769.5	768.2	719.3	634.8	502.5	376.1	68.7		3
45									748.9	685.4	553.6	406.2	175.7	1.8	1.9	
46									720.8	640.8	457.7	289.9	7.7	1.5	1.6	
47									698.8	584.6	348.2	154.6	1.1	1.2	1.3	
48									661.0	519.5	224.5	.9	.9	1.1	1.1	
49									613.3	431.9	163.0	.7	.8	.8	.9	
50									554.7	332.3	8.1	.6	.6	.7	.7	

BASIC TREE	0	1	10	14	13	5	3	7	1	2						

GROSS SCRIBNER BOARD FOOT VOLUME TO 6 INCH TOP DIB -UNMARKED TREES
WHITE FIR
SANTA FE-CARSON N.F.

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	BASIS TREES
7	.7	1.2	1.8	2.4	2.9	3.5	4.1									0
8	1.8	3.7	5.7	7.6	9.5	11.5	13.4	15.3								0
9	3.2	6.8	10.5	14.1	17.8	21.4	25.1	28.7	32.4							1
10		10.4	16.1	21.7	27.4	33.0	38.7	44.4	50.0							2
11		14.4	22.3	30.2	38.2	46.1	54.0	61.9	69.9	77.8						2
12		18.7	29.2	39.6	50.1	60.5	71.0	81.4	91.8	102.3						2
13		23.5	36.7	49.9	63.1	76.3	89.4	102.6	115.8	129.0	142.2					4
14		28.6	44.8	61.0	77.1	93.3	109.5	125.6	141.8	158.0	174.1					3
15			53.5	72.9	92.3	111.7	131.1	150.4	169.8	189.2	208.6	227.9				3
16			62.9	85.7	108.5	131.3	154.2	177.0	199.8	222.6	245.4	268.2				4
17			72.8	99.3	125.8	152.3	178.8	205.3	231.8	258.2	284.7	311.2	337.7			3
18			83.4	113.8	144.2	174.6	205.0	235.3	265.7	296.1	326.5	356.9	387.3			1
19			94.6	129.1	163.6	198.1	232.7	267.2	301.7	336.2	370.7	405.2	439.7	474.2		2
20				145.3	184.2	223.0	261.9	300.8	339.6	378.5	417.4	456.3	495.1	534.0		2
21				162.3	205.8	249.2	292.7	336.2	379.6	423.1	466.6	510.0	553.5	596.9	640.4	2
22				180.2	228.5	276.7	325.0	373.3	421.6	469.9	518.2	566.5	614.8	663.1	711.3	2
23				198.9	252.2	305.6	358.9	412.3	465.6	518.9	572.3	625.6	679.0	732.3	785.6	3
24				218.5	277.1	335.7	394.4	453.0	511.6	570.2	628.9	687.5	746.1	804.7	863.4	2
25					303.1	367.2	431.3	495.5	559.6	623.8	687.9	752.1	816.2	880.4	944.5	1
26					330.1	400.0	469.9	539.8	609.7	679.6	749.5	819.4	889.3	959.2	1029.1	2
27					358.2	434.1	510.0	585.9	661.8	737.6	813.5	889.4	965.3	1041.2	1117.0	0
28					387.5	469.6	551.7	633.8	715.9	798.0	880.1	962.1	1044.2	1126.3	1208.4	1
29					417.8	506.3	594.9	683.4	772.0	860.5	949.1	1037.6	1126.2	1214.7	1303.2	0
30						544.4	639.7	734.9	830.1	925.4	1020.6	1115.8	1211.0	1306.3	1401.5	0
31						583.9	686.0	788.2	890.3	992.5	1094.6	1196.7	1298.9	1401.0	1503.2	0
32						624.6	733.9	843.2	952.5	1061.8	1171.1	1280.4	1389.7	1499.0	1608.3	0
33						666.7	783.4	900.1	1016.8	1133.4	1250.1	1366.8	1483.5	1600.1	1716.8	0
34						710.1	834.4	958.7	1083.0	1207.3	1331.6	1455.9	1580.2	1704.5	1828.8	0
35							887.0	1019.2	1151.3	1283.5	1415.6	1547.8	1679.9	1812.1	1944.2	0
36							941.2	1081.4	1221.7	1361.9	1502.1	1642.3	1782.6	1922.8	2063.0	0
37							996.9	1145.5	1294.0	1442.6	1591.1	1739.7	1888.2	2036.8	2185.3	0
38							1054.2	1211.3	1368.4	1525.5	1682.6	1839.7	1996.8	2153.9	2311.0	0
39							1113.1	1279.0	1444.9	1610.7	1776.6	1942.5	2108.4	2274.3	2440.2	0
40								1348.4	1523.3	1698.2	1873.1	2048.0	2223.0	2397.9	2572.8	0
41								1419.7	1603.8	1788.0	1972.2	2156.3	2340.5	2524.6	2708.8	0
42								1492.7	1686.4	1880.0	2073.7	2267.3	2461.0	2654.6	2848.3	0
43								1567.6	1771.0	1974.3	2177.7	2381.1	2584.4	2787.8	2991.2	0
44								1644.3	1857.6	2070.9	2284.2	2497.5	2710.9	2924.2	3137.5	0
45									1946.2	2169.7	2393.3	2616.8	2840.3	3063.8	3287.3	0
46									2036.9	2270.8	2504.8	2738.7	2972.7	3206.6	3440.5	0
47									2129.6	2374.2	2618.8	2863.4	3108.0	3352.6	3597.2	0
48									2224.4	2479.9	2735.4	2990.9	3246.3	3501.8	3757.3	0
49									2321.2	2587.8	2854.4	3121.0	3387.7	3654.3	3920.9	0
50									2420.0	2698.0	2976.0	3254.0	3531.9	3809.9	4087.9	0
BASIS TREES	0	0	0	7	10	6	2	5	1	0	0	0	0	0	0	

NET SCRIBNER BOARD FOOT VOLUME TO A 7 INCH TOP DIB
WHITE FIR
SANTA FE-CARSON N. .

DBH CLASS	HEIGHT CLASS 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	PAGE TOTAL
7	.6	1.2	1.7	2.2	2.8	3.3	3.8									
8	1.7	3.5	5.3	7.0	8.8	10.6	12.4	14.2								
9	2.9	6.2	9.6	12.9	16.2	19.5	22.9	26.2	29.5							
10		9.3	14.4	19.5	24.5	29.6	34.6	39.7	44.7							
11		12.7	19.6	26.6	33.5	40.5	47.4	54.3	61.2	68.1						
12		16.2	25.2	34.2	43.1	52.0	61.0	69.8	78.7	87.6						
13		19.9	31.0	42.1	53.1	64.1	75.1	86.1	97.2	107.9	118.7					
14		23.7	37.1	50.3	63.6	76.7	89.8	102.9	115.9	128.9	141.8					
15			43.3	58.9	74.3	89.7	105.0	120.2	135.4	150.4	165.4	180.2				
16			49.8	67.7	85.5	103.1	120.6	138.0	155.3	172.5	189.5	206.4				
17			56.6	76.9	97.0	116.9	136.7	156.3	175.7	195.0	214.1	233.0	251.6			
18			63.6	86.4	108.9	131.2	153.3	175.1	196.7	218.2	239.1	259.9	280.5			
19			70.9	96.2	121.2	146.0	170.4	194.4	218.2	241.6	264.6	287.2	309.6	331.6		
20				106.5	134.1	161.2	188.0	214.2	240.2	265.6	290.6	315.1	339.1	362.5		
21				117.2	147.4	177.0	206.2	234.8	262.8	290.2	317.0	343.2	368.7	393.5	417.7	
22				128.3	161.2	193.4	225.0	255.8	285.9	315.2	343.8	371.5	398.4	424.4	449.6	
23				139.9	175.5	210.4	244.3	277.4	309.5	340.7	370.9	400.1	428.1	455.1	481.8	
24				151.9	190.4	227.9	264.2	299.5	333.6	366.5	398.2	428.5	457.5	485.1	511.7	
25					205.8	245.9	284.7	322.1	358.1	392.6	425.5	456.8	486.4	514.2	540.1	
26					221.7	264.4	305.6	345.1	382.8	418.7	452.7	484.7	514.5	542.7	567.5	
27					238.0	283.5	327.2	368.4	407.8	444.8	479.6	511.8	541.5	568.5	592.6	
28					254.8	302.9	348.6	391.9	430.7	470.7	505.9	538.1	567.1	591.6	614.8	
29					272.1	322.7	370.6	415.6	457.5	496.1	531.3	564.8	591.5	614.1	635.4	
30						342.8	392.7	439.2	481.9	520.8	555.5	585.8	611.5	632.1	647.7	
31						363.1	414.9	462.6	505.9	544.5	578.7	606.6	629.4	645.2	656.7	
32						383.6	437.1	485.7	529.1	567.1	599.	624.7	641.7	655.5	659.5	
33						404.3	459.0	508.9	551.4	588.3	617.5	639.6	651.6	658.9	655.1	
34						424.7	480.8	530.1	572.4	607.7	633.3	651.6	658.3	655.	644.	
35							502.7	551.1	591.9	623.6	645.1	65 .	65 .	644.6	618.9	
36							522.7	571.3	609.6	637.4	654.1	658.7	648.1	627.5	584.3	
37							542.7	589.6	625.5	648.4	658.	654.	631.	599.8	536.4	
38							561.8	607.6	638.3	655.6	657.1	644.	606.6	551.7	477.	
39							579.8	621.7	648.4	658.5	651.	621.	570.7	489.8	391.	
40								634.6	655.3	656.5	636.3	582.	514.	411.7	291.5	
41								645.1	658.4	649.1	614.8	551.8	459.9	317.	180.7	
42								651.8	651.7	635.5	584.7	501.6	388.	214.	68.8	
43								657.2	651.1	614.9	544.9	437.	306.8	99.	1.	
44								658.1	639.6	586.4	494.	357.6	205.5	1.	1.	
45									621.9	549.	431.8	276.	96.6	1.	1.	
46									597.5	501.8	358.7	179.	1.	1.	1.	
47									565.4	441.5	261.1	79.4	1.	1.	1.	
48									524.8	370.9	151.1	1.	.9	1.0	1.	
49									474.7	288.5	41.7	1.	1.	1.	1.	
50									413.2	188.8	1.	1.	1.	1.	1.	
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EFFECTS OF BURNING MOIST FUELS ON SEEDBED PREPARATION IN CUTOVER WESTERN LARCH FORESTS

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CONTENTS

INTRODUCTION 1

LITERATURE 2

STUDY AREA AND TREATMENT 2

METHODS 5

Duff Reduction and Mineral Soil Exposure 5
Soil Water 7
Soil Heating 7
Root Kill 7

RESULTS AND DISCUSSION 7

Prescribed Fires 7
Duff Water 9
Soil Water 10
Soil Temperatures 11
Root Mortality 11

MANAGEMENT APPLICATION 12

PUBLICATIONS CITED 13

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RESEARCH SUMMARY

In early September 1975, two clearcuts (14 and 17 acres; 5.7 and 6.9 ha), two sets of 4 small clearcuts (<1.5 acres; 0.6 ha each), and one shelterwood cutting (22 acres; 8.9 ha) were broadcast burned principally for seedbed preparation and fuel reduction on the Coram Experimental Forest. The objective was to develop a model for predicting duff reduction (amount and percent) and mineral soil exposure (percent) resulting from the fires, using only preburn measurements for inputs. In addition, the influence of the fires on soil heating, soil water content, and nonconiferous root mortality was quantified.

Because of the relatively low maximum air temperatures and high precipitation on the study area during August, the fuels were relatively moist at the time of ignition. As a result, the fires generally spread poorly, especially in the shelterwood, except where the fuels were concentrated. The prescribed fires reduced the duff an average of 27 percent in the clearcuts and 11 percent in the shelterwood. Mineral soil exposure averaged 19 percent in the clearcuts and 10 percent in the shelterwood. The amount of water within the upper 4 inches (10.2 cm) of soil was not changed greatly, there was no significant heating of the surface soil above 113°F (45°C), and root mortality was low.

Multivariate regression analysis was used to derive prediction equations for duff reduction and mineral soil exposure. However, because of extremely poor correlation between the dependent variables, duff reduction and mineral soil exposure, and all combinations of the independent variables, no statistically valid equations resulted. The expected correlation between duff consumption and lower duff water content was not evidenced. This was attributed to the high water content of the duff itself, which averaged nearly 150 percent in the three blocks studied. These results substantiate Shearer's (1975) conclusions. Broadcast burning for seedbed preparation should not be attempted in this forest type when lower duff water contents exceed about 100 percent.

INTRODUCTION

Natural seeding is normally the preferred method of regenerating conifers in the thern Rocky Mountains (Schmidt and Shearer 1973). Some seedbed preparation is ally necessary for successful natural regeneration. Shade intolerant species such western larch (*Larix occidentalis* Nutt.) regenerate best on bare mineral soil.

In northwestern Montana, broadcast burning for seedbed preparation is commonly cticed in western larch--Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] nco) stands. Prescribed fire is preferred over mechanical scarification because: it normally costs less (Boyd and Deitschman 1969); (2) it recycles nutrients back o the soil, ultimately resulting in increased tree growth rates (western larch trees to 13 years old grew about one-third faster on broadcast burned areas than on dozer rified seedbeds (Schmidt 1969); and (3) it is usually the most practical method for e preparation on steep slopes.

The amount of seedbed preparation desired (or achieved) is best expressed by min- l soil exposure. However, no conclusive quantitative data on the spatial distribu- n of mineral soil exposure by broadcast burning are available. Instead, research generally focused on measurements of duff layer consumption. The postfire seedbed dition can be more meaningfully expressed by an estimate of both duff reduction and spatial distribution of exposed mineral soil. Research has not provided adequate des for managers to prescribe fires that expose a specified percent of mineral soil. ethod is needed to simply and accurately predict the quality of seedbed preparation burning.

The study reported here is part of a Research and Development Program evaluating ernative residue utilization and disposal treatments, one of which is burning. The ective of this study was to develop regression equations, using only preburn measure- t input, for both duff reduction and the amount of mineral soil exposed by prescribed e for clearcut and shelterwood silvicultural systems. The prescription goal for the es was a 2-inch reduction of the duff layer. This would have resulted in an overall n duff depth reduction of about 50 percent, and provided the minimum 30 percent min- l soil exposure desired. Prescribed conditions deemed necessary to achieve the ective were as follows:

SHELTERWOOD BLOCK	*RANGE*
0-1 inch (0-2.54 cm) diameter dead fuel water content	10-15%
Upper duff water content	40-60%
Windspeed	0-5 mi/h (0-8.05 km/h)
Air temperature	70°F (21.1°C) or less
Relative humidity	25% or above; steady or rising
Time of day	1400 or later

CLEARCUT BLOCKS	*RANGE*
0-1 inch (0-2.54 cm) diameter dead fuel water content	12-15%
Upper duff water content	25-40%
Windspeed	0-10 mi/h (16.09 km/h); steady to diminishing
Relative humidity	25% or above, steady or rising

In addition, the influence of the prescribed fires on soil heating, soil water content, and root mortality of nonconifers was estimated. These data provided an estimate of the amount of mineral soil exposed and a forecast of early vegetative competition.

LITERATURE

Research on duff consumption has been related to either duff water or to indices of fire danger or drought (Artley 1976). Because measurements of physical parameters (such as duff water content) enhance consistent interpretation over time, and decrease the chance of interpretive error, they are probably more useful in describing duff consumption.

Duff moisture has repeatedly been used in research describing and predicting duff reduction by fire. Early investigations related duff reduction to a subjective estimate of duff moisture content (Sweeny and Biswell 1961; Morris 1966). Later attempts explained duff consumption by precisely measuring the variables thought to be the most important contributors. For example, Hough (1968) and Steele and Beaufait (1969) determined that measurements of the moisture content of the litter, the duff, and the woody fuel, all were useful in predicting duff reduction. More recently, emphasis had shifted to the use of multivariate regression analysis and correlation analysis in order to formulate prediction equations for duff reduction. Van Wagner (1972) found that the best predictor of duff weight consumed by fire in eastern pine stands is duff moisture content and is more closely related to duff consumption than measurements of actual fire behavior.

Similar results have been reported from prescribed fire studies in three different areas within western larch forests of northwestern Montana. Duff consumption is linearly related to the moisture content of the lower half of the duff when it is between the range of approximately 40 to 110 percent (Shearer 1975). Steele (1975) attributed duff consumption to preburn duff depth, duff moisture content, and the weight of the woody shrubs. Norum (1975, 1977) concluded that duff reduction was dependent on the factors above the duff which most influenced fire intensity and persistence, in addition to the moisture content of the lower duff. Van Wagner (1965) also found that mineral soil exposure increased as fire intensity increased. Similarly, Beaufait and others (1977) showed a strong relationship between the water loss from a water can analog (Beaufait 1966; George 1969) and duff consumption. In addition, they concluded that duff reduction by fire was a function of the moisture content of the upper half of the duff.

STUDY AREA AND TREATMENT

The study was conducted on the 7,460 acre (3,019 ha) Coram Experimental Forest, on the Flathead National Forest, in northwestern Montana (fig. 1). The study sites are located below the main ridge facing east into Abbot Basin (lat. 48° 25' N., long. 113° 59' W.). Six blocks, consisting of two clearcuts (14 and 17 acres; 5.7 and 6.9 ha), two shelterwoods (35 and 22 acres; 14.2 and 8.9 ha), and two sets of eight small clearcuts (average 0.8 acre; 0.3 ha, range from 0.3 to 1.4 acres; 0.1 and 0.6 ha), were

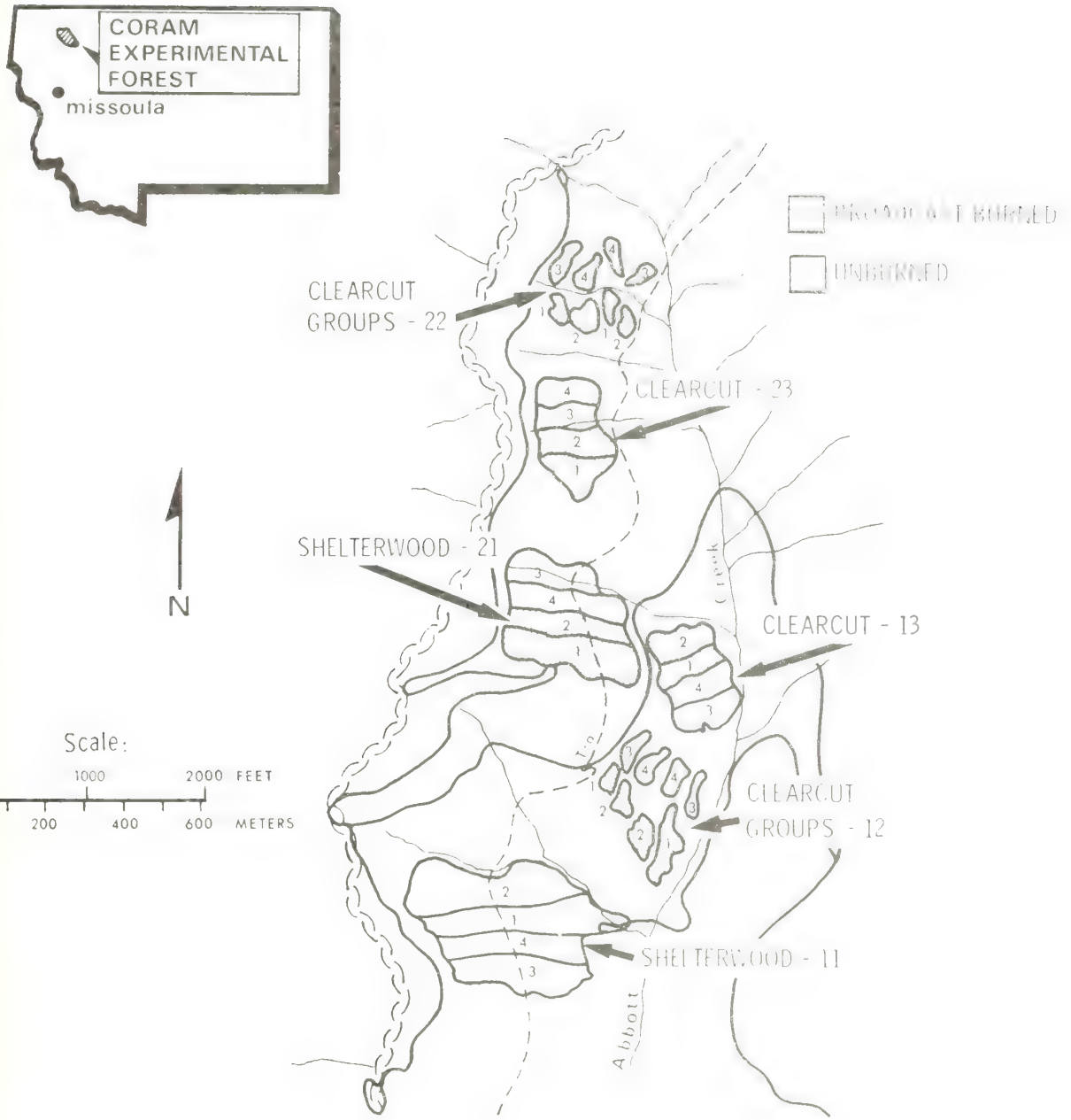

Figure 1.--Location of cutting [illegible] Timber harvested in 1974 and broadcast [illegible].

Figure 2.--Prescribed broadcast burning of clearcut 13 on Coram Experimental Forest. Only half of each cutting was burned.

logged in 1974. Each block was further divided into four subblocks, in which four different standards of timber and residue utilization were employed (fig. 1). Of the four subblocks, only No. 1 and 2 were broadcast burned (fig. 2), and this study was limited to them. A description of the two utilization standards applied to the burned subblocks in each block follows:

Subblock	*Trees Cut*	*Utilization Standard*
1	All trees except designated overstory shelterwood trees	All material (live and dead, standing and down) to 3 inch (7.6 cm) dia., 8 foot (2.4 m) length, and 1/3 sound removed.
2	All trees except designated overstory shelterwood trees.	Sawtimber material (live and recently dead) to 1974 Forest Service standards: 7 inch (17.8 cm) d.b.h., 8 foot (2.4 m) length, and 1/3 sound removed.

The timber type on the study area is larch--Douglas-fir (Cover Type 212, Society of American Foresters 1954). This type is composed primarily of western larch and Douglas-fir. Associated species include subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.)

d Engelmann spruce (Parry). The study area falls primarily in the
ies lasiocarpa/Clintonia uniflora habitat type, with the following phases represented
alia nudicaulis, *Menziesia ferruginea*, *Clintonia uniflora*, and *Xerophyllum tenax*
Fister and others 1977; Bernard L. Kovalchik 1974, unpublished data).

The topography ranges in steepness from 30 to 80 percent (17° to 39°), while the
evation ranges from 3,900 to 5,200 feet (1,189 to 1,585 m) m.s.l. The soils on the
opes are derived from impure limestone and underlying material of loamy-skeletal soil
milies (Klages and others 1976).

METHODS

Before logging, 10 permanent points were systematically located at 100-foot inter-
ls within each of the subblocks in the clearcut and shelterwood cuttings. Five
ints were located within each of the eight small clearcuts at variable intervals
pending on size of the opening. All plots were referenced to these points.

Duff Reduction and Mineral Soil Exposure

Fifty 4 by 4 ft (1.2 by 1.2 m) plots were randomly located in each subblock (five
ferenced to each permanent point), of the shelterwood and clearcut blocks (none were
tablished in the small clearcuts). At each plot the following preburn measurements
re taken (fig. 3).

1. Duff depth (not including the litter layer)

2. Mineral soil exposure (percent of area)

3. Weight per unit of area of downed woody material in each of the following size classes (Brown 1974):

   a. 0-0.25 inch (0-0.64 cm) diameter
   b. 0.25-1.00 inch (0.64-2.54 cm) diameter
   c. 1-3 inch (2.54-7.62 cm) diameter
   d. Greater than 3 inch (7.62 cm) diameter, sound
   e. Greater than 3 inch (7.62 cm) diameter, rotten.

4. Woody shrub weight (Brown 1976)

5. Depth of down woody material

6. Slope

7. Aspect.

Figure 3.--Preburned slash measurements being taken on clearcut 13, June 26, 1975. Note relatively light fuel volume.

Approximately 1 hour prior to the ignition of each fire, samples of the following material were gathered at each of the permanent points:

1. Duff (upper and lower half sampled separately)
2. Downed woody material in the 0-0.25 inch (0-0.64 cm) and 0.25-1 inch (0.64-2.54 cm) diameter size classes
3. Herbaceous vegetation.
   Samples were weighed, dried, and reweighed to determine the preburn water content of each.

After the fires, the plots were relocated and the following measurements were taken:

1. Duff depth
2. Mineral soil exposure (percent of area)
3. Weight per unit area of each of the five diameter size classes of downed woody material
4. Depth of downed woody material.

Each of the preburn measurements was designed as a potential independent variable for a regression analysis on duff reduction and mineral soil exposure.

Soil Water

The percent of water (by weight) held within the surface inch of soil was estimated ravimetrically the day of, and the morning after each fire. At t 10 of these sampling points soil water was also estimated within the 1- to 4-inch 2.54- to 10.16-cm) level. The results indicated the amount of water gained through ondensation or lost by vaporization as a result of the broadcast fires.

Soil Heating

The maximum temperature within the upper 6 inches (15.2 cm) of soil was estimated y using Tempilaq (Tempil Division, Big Three Industries, Inc., South Plainfield, N.J.). ectangular asbestos strips having six full-length depressions scored on both sides ere used. Each depression was filled with Tempilaq of a different melting point be- ween 113°F (45°C) and 500°F (246°C). One strip was referenced to each of the 20 per- anent points and the upper edge of each strip was positioned along the soil-duff nterface.

Root Kill

On the day of burning, the numbers of dead and living roots were counted at the ame 10 locations where the preburn soil water samples were taken down to the 0 to inch (0 to 10.16 cm) level. This consisted of exposing a vertical face of soil 0 inches (25.4 cm) wide and 6 inches (15.2 cm) deep. This surface was sprayed with rthotolidine solution (Shearer 1975) that indicated which roots were respiring living). The numbers of living and dead roots greater than 0.05 inch (0.13 cm) in iameter at this interface were counted. Living and dead roots were counted again bout 2 weeks after burning, near the point where the postfire soil water samples were aken. Both the numbers of dead and living roots were recorded.

RESULTS AND DISCUSSION

Prescribed Fires

The burning was accomplished during the period from September 8 through September 3, 1975 (fig. 1 and 4). No block was burned entirely within the prescription estab- ished for duff reduction and mineral soil exposure (see p 1) because (1) cool, wet onditions prevailed for several weeks prior to burning preventing drying of fuel, and 2) burning could not be postponed for a year due to time requirements imposed on the &D Program to complete its overall research objective. Block 11 (shelterwood) was ot burned because both the preburn fuel and the duff water samples were above pre- cription limits (see p. 2). In each of the other units, preburn sampling indicated hat the 0.0 to 1 inch (0.0 to 2.54 cm) diameter fuels were within prescription imits, while the upper duff water content was consistently too high (table 1).

Figure 4.--Prescribed broadcast burning of the shelterwood on Coram Experimental Forest. Slash and duff were moist as indicated by little flame and heavy smoke.

Table 1.--*Preburn water content*[1] *of woody fuels, duff, and herbaceous vegetation.*

Block	0-1/4 inch dia. fuels	1/4-1 inch dia. fuels	Upper duff	Lower duff	Herbaceous vegetation
	Percent				
Shelterwood (21)	17	[2]21	[2]81	148	225
Small clearcuts (12)	14	15	48	86	205
Small clearcuts (22)	15	14	47	111	210
Clearcut (13)	15	15	[2]98	146	241
Clearcut (23)	14	14	[2]74	164	245

[1]Mean values for 20 sample points.

[2]Above prescription limits (lower duff and herbaceous vegetation limits were not prescribed).

Table 2.--*Mean duff reduction and mineral soil exposure on each subblock*

Block	Sample No.	Mineral soil exposure	Duff	Duff reduction
			Inches	
Shelterwood [1](21-1)	40	7	[2]	[2]
Shelterwood [1](21-2)	34	13	[2]	18
Small Clearcuts (12)	20	(2)	1.1	14
Small Clearcuts (22)	20	(2)	.8	28
Clearcut (13)	91	18	.7	27
Clearcut (23)	90	20	.7	26

[1]Shelterwood subblock mean values were not similar enough statistically to allow the subblocks to be combined.

[2]No data--mineral soil exposure was not estimated.

The fires did not spread well because of frequent fuel discontinuity, especially in subblock 1, which had lighter fuel. Subblock 2 of each block burned more completely and evenly as a result of heavier fuel loading. However, usually only the fine fuels and litter were consumed. Within each block a number of plots did not burn, and these were lost for analysis (9 and 10 out of 100 in each of the two clearcuts, and 26 of 100 in the shelterwood).

Duff Reduction and Mineral Soil Exposure

Table 2 summarizes the mean duff depth reduction and mineral soil exposure on each subblock. The percentage of mineral soil exposed ranged from a high of 20 percent on clearcut block 23 to a low of 7 percent on shelterwood subblock 21-1, falling short of the 30 percent minimum prescribed. Mean duff depth reduction was less than 0.8 inch (2.03 cm) in all blocks, amounting to a reduction of approximately 25 percent. The prescription called for a 2-inch (5.08-cm) reduction to provide for an overall mean duff depth reduction of about 50 percent. Again prescription goals were not met.

These results are primarily attributed to the high water content of the duff layer, especially in the lower half. Upper duff water content was above prescription limits in both the clearcuts and the shelterwood, and except for block 12, lower duff water content exceeded 100 percent in all blocks.

The Rex--Fortran-4 computer program (Grosenbaugh 1967) was used for both combinatorial screening and conventional multivariate regression analysis. Both mineral soil exposure and duff reduction were tested against all possible combinations of independent variables, up to and including sets of four. In all cases, R^2 values were so low that no relationships were indicated. Various transformations and combinations of variables were also tried with no significant improvements. Therefore, no regression equations are presented.

Duff Water

The water content of the duff, especially of the lower half, has been repeatedly shown to be a major influence in the reduction of the duff layer by fire (Norum 1975, 1977; Shearer 1975; Van Wagner 1972). However, the results of this study show no relationship between them, because of the magnitude of the water contents. Shearer (1975), working in the same forest type, found that duff reduction in percent is related to lower duff water, only when the latter is between 50 and 110 percent (fig. 5).

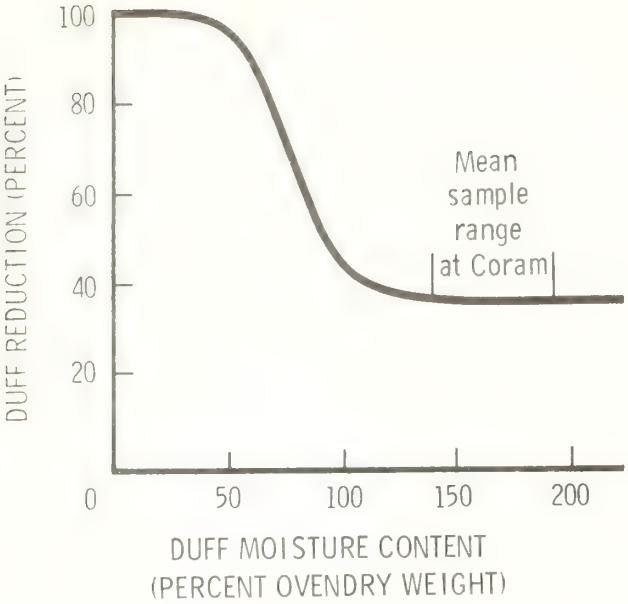

Figure 5.--Duff reduction related to the water content of the lower half of the duff layer (from Shearer 1975).

At 50 percent water content, the duff layer is mostly burned off, but as the water content increases, a decreasing percentage of the duff layer is consumed. Above 110 percent, however, duff reduction drops to a uniformly low amount.

When the results of this study are superimposed on Shearer's curve, it is not surprising that lower duff water content had no significant correlation to duff consumption. In the clearcuts, lower duff water averaged 155 percent, with a range from 71 to 275 percent. The shelterwood averaged 148 percent with a range from 77 to 205 percent. The range of the subblock mean lower duff water contents (140 to 188 percent) is plotted on figure 5 in order to clearly show that the conditions as sampled were outside of the predictive portion of the curve.

The unusually high duff moisture resulted from the high precipitation and low temperature on the Coram Experimental Forest during August 1975, the month preceding the fires. During that month there was a total of 4.07 inches (10.34 cm) of precipitation, twice the normal mean, and the average daily maximum temperature was 66.9°F (19.3°C), approximately 2°F (1.2°C) below normal. This was the coldest August ever recorded at the Hungry Horse Dam, and the third wettest since records were started in 1947.

Soil Water

None of the prescribed fires greatly changed the amount of water within the surface 4 inches (10.16 cm) of soil; within the upper inch (2.54 cm), the average was 27.1 percent before, and was 26.8 percent after fires. Of the 398 samples taken within the surface inch during the week of burning, 63 percent contained 20 to 30 percent water, while 15 percent contained less than 20 percent water and 22 percent contained greater than 30 percent water. Nearly half of the samples within the surface inch increased in water following burning, probably indicating a zone of condensation similar to that described by Uggla (1973).

The amount of water within the surface inch of soil varied significantly by cutting method. The average amount of water was least within the shelterwood cutting, intermediate within the small clearcut groups, and greatest within the clearcuts. In addition, the average amount of water increased (but not significantly) with greater elevation by type of cutting.

The surface inch of soil had slightly, but significantly, higher water content under heavier concentrations of slash, probably because of less evaporation from the soil due to greater shading. Soil water averaged 28 percent under heavy slash and 26 percent under light slash.

Soil Temperatures

Prescribed fires caused little heating within the surface soil (table 3). The clearcuts and groups of small clearcuts burned more completely than the burned shelterwood cutting. Soil heating was greatest at the soil surface on block 23 (upper clearcut), where 60 percent of the sample points reached at least 113°F (45°C); only 20 percent of these points reached 138°F (58.9°C) (near the lethal temperature for living plant tissue). The greatest depths that reached 113°F (45°C) and 138°F (58.9°C) were 2.4 inches (6.10 cm) and 1.4 inches (3.56 cm), respectively. Rarely did the surface soil reach 200°F (93.3°C).

Root Mortality

Low soil warming associated with the prescribed fires caused low root mortality, even within the surface 1 inch of soil (table 4). Least root mortality occurred under the shelterwood cutting where much of the block failed to burn. Because of the low root mortality near the surface, recovery of perennial plants from root sprouts was prolific in 1976 on all burned areas.

Table 3.--*Maximum and average soil temperatures recorded by thermocouples and depth of penetration of temperatures equal to or exceeding 113°F (45°C) and 138°F (58.9°C) by Tempilaq melt during prescribed fires, September 1975, Coram Experimental Forest*

Block		Sample points burned[1]	113°F			138°F			200°F		
			Max	Ave	Points	Max	Ave	Points	Max	Ave	Points
		Percent	*--Inches--*		*Percent*	*--Inches--*		*Percent*	*--Inches--*		*Percent*
Shelterwood[2]	(11)	0	--	--	--	--	--	--	--	--	--
Shelterwood	(21)	50	1.3	0.1	10	0.6	<0.1	5	0.0	0.0	0
Small Clearcuts	(12)	85	1.4	.2	45	.6	.1	5		< .1	5
Small Clearcuts	(22)	85	.0	.0	0	.0	.0	0	.0	.0	0
Clearcut	(13)	100	.8	.2	50	.3	< .1	15	.0	.	
Clearcut	(23)	90	2.4	.3	60	1.4	.1	20	.	< .1	5

[1]Twenty points sampled in each block.
[2]Shelterwood block 11 not burned.

Table 4.--*Mortality of nonconifer roots (percent) in the surface inch of soil, before and after prescribed burning, by cutting method, Coram Experimental Forest*

Cutting method		Living root		Mortality
		Before	After	
Shelterwood	(11)	80		
Shelterwood	(21)	82	76	6
Small clearcuts	(12)	85	65	20
Small clearcuts	(22)	88	50	38
Clearcut	(13)	80	44	36
Clearcut	(23)	92	76	16

[1]Not burned.

MANAGEMENT APPLICATION

The broadcast burning of moist fuels produces large variation in duff depth reduction and mineral soil exposure, even across relatively similar areas. Because mean values were small, standard deviations for each consistently approached the means in the clearcut, and exceeded them in the shelterwoods. Differences in variation were found to be primarily within each block rather than between blocks. In addition, the fires failed to heat or to dry the surface soil sufficiently to significantly reduce the root sprouting potential of competing nonconiferous species.

The hypothesis that the high water content of the duff influenced the expected relationships is strengthened when weather patterns for the area are examined. Although August 1975 was the coldest and one of the wettest on record, this combination of a low temperature with heavy precipitation has occurred in this area seven times in the past 29 years. Because this situation occurs about one year out of four, the possibility of extremely wet duff conditions should be considered when planning September fires.

The lack of correlation between lower duff water content and percent duff reduction substantiates Shearer's (1975) and Norum's (1977) conclusions. Therefore, with a mean lower duff water content of greater than 100 percent, broadcast burning for duff reduction should probably not be attempted in this forest type.

The burned areas revegetated quickly in 1976 from rhizomes, root crowns, and underground stems. Growth was enhanced by the large supply of available nutrients released during the fires. Trees and other vegetation relying on seed for regeneration were at a competitive disadvantage because of the density of plants sprouting from underground parts. Regeneration of shade-intolerant conifers will be difficult because of generally unfavorable seedbed conditions and intense competition for light and water. A few western larch that germinated in 1975 survived within unburned areas and will probably form a part of the dominant tree canopy within a few years. It is doubtful that many other shade-intolerant conifers will survive this competition. Gradually the more shade-tolerant subalpine fir, western hemlock (on lower slope moist sites), and Douglas-fir (on drier sites) will establish and complete a new stand. Later papers will discuss (1) development of vegetation (including trees) within each cutting method and residue treatment, and (2) effects of broadcast fires on residual trees.

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Two large clearcuts, eight small clearcuts, and one large shelterwood cutting in a larch-fir forest in northwestern Montana were broadcast burned following alternative residue utilization and disposal treatments. The fires failed to substantially reduce the duff or expose much mineral soil because of low maximum temperatures and high precipitation prior to burning. Changes in soil water, soil heating, and root mortality associated with the fires were minimal.

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MOISTURE CONTENT OF LUMBER PRODUCED FROM DEAD WESTERN WHITE PINE AND LODGEPOLE PINE TREES

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CONTENTS

INTRODUCTION . . .

WESTERN WHITE PINE 1

Methods 1
Results and Discussion . . .

LODGEPOLE PINE . . . . . .

Methods 5
Results and Discussion 6

CONCLUSIONS . . . . . .

RECOMMENDATIONS 9

PUBLICATIONS CITED 11

RESEARCH SUMMARY

One of the Rocky Mountain area's major problems is the utilization of insect- and disease-killed timber. More and more of these trees are being harvested as a part of green timber sales. The efficient handling and processing of this material depends to a large extent on its moisture content.

In the two studies reported here, the moisture content of lumber sawed from dead western white pine and lodgepole pine logs was determined using both a moisture meter and the ovendry test method. In both studies the moisture content of lumber from dead trees was about half that reported for green lumber of the same species. Test sections cut from a sample of the boards showed that the dead log lumber had essentially no moisture gradient and only a slight amount of drying stress.

This information indicates the kiln drying time for dead log lumber should be about half the time required to dry green lumber. A dry kiln operator can determine the appropriate drying conditions for a charge of dead lumber by measuring its moisture content with a moisture meter.

INTRODUCTION

Within recent years, disease and insects have killed numerous western white pine
nus monticola Dougl.) and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.)
es in the timber stands of Idaho and Montana. Estimates place the annual mortality
all softwood species in these two States at about 350 million cubic feet and for
tern white pine alone at 60 million cubic feet. About 10 percent of the dead trees
salvaged as a part of ongoing timber sales. The logs from these trees are usually
cessed with green logs and the lumber is intermixed for drying and surfacing.

This practice may not be the best since the lumber from the dead trees usually
a much lower moisture content than the lumber made from green logs. With ever-
reasing energy costs, the present procedure is uneconomical with longer kiln dwell
ie than is necessary for the lumber from the dead logs and excessive degrade of this
erial by overdrying.

The objective of this study was to determine the moisture content, before drying,
lumber made from dead white pine and lodgepole pine logs. The moisture content was
isured using both a moisture meter and the standard ovendry test. The results were
ipared to determine accuracy and consistency between the two methods. Small sections
from sample lumber were tested for moisture gradient and drying stress. In addition,
few moisture meter readings were obtained from the lodgepole pine studs after kiln
ying. This information was used to evaluate the drying methods and determine if
anges would be desirable. Each of the study species was processed at a single mill
d the results of the two studies are discussed separately.

WESTERN WHITE PINE

Methods

A sawmill in north Idaho was selected for the white pine study. The mill's proce-
re was to segregate the dead tree logs in the mill yard and when a sufficient volume
d been accumulated, process the logs in 1 or 2 days' time. The mill, equipped with a
rcular saw, cut dead logs into dimension lumber, primarily 2 by 4's and 2 by 6's,
th a few 1 inch sideboards being produced as well. On the green chain, the lumber,
random length, was box piled and stickered for kiln drying.

Four packages of lumber were selected at the green chain for study. Three of t packages were 2 by 4's and a fourth was 2 by 6's, reflecting the approximate proport of a day's production. The moisture content was measured with a resistance-type me equipped with a four-needle, 1/2-inch-long probe. Three moisture meter readings wer taken from each board in the sample packages approximately 2, 6, and 10 feet from on end. Later the moisture meter readings were adjusted for temperature and an average reading for each board calculated. In addition, a subsample containing 10 boards fr package No. 2, 9 boards from package No. 3, and 6 boards from package No. 4 was sele at random for destructive sampling. Package No. 1 was not available at the time thi subsample was selected so packages 2 and 3 were more heavily sampled than package 4 make up for this deficiency.

Four pieces, approximately 20 inches long, were cut from each of the subsample boards. The pieces were cut 2 and 6 feet from each end of the board. These pieces, identified as to board, were placed in polyethylene bags and carried to the shop wh three sections about an inch long, were cut from near the center of each piece (fig.

The first section of each board, which we labeled the A sections, was left inta and used to determine the moisture content by the standard ovendry test. The B sect were further cut into shells and cores (fig. 1B) and used to determine the moisture distribution by the ovendry method. The C sections were sliced into four prongs (fi 1C) and placed on a table in the shop where they were permitted to dry at room tempe ture. These drying stress sections were examined periodically to determine the pres of any casehardening or reverse casehardening.

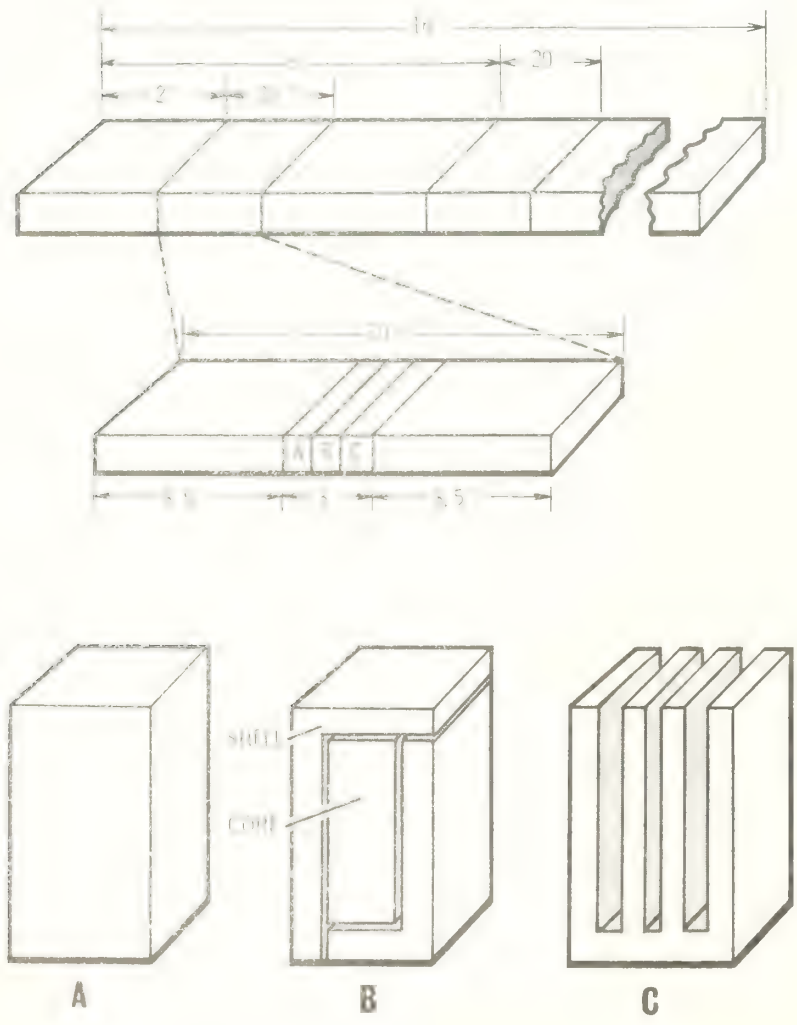

Figure 1.--Schematic showi how board pieces and sec tions were cut. Section A, B, and C are end view A is moisture content se tion, B is moisture dist bution section, and C is drying stress section.

Results and Discussion

The temperature-corrected moisture meter readings indicate that the moisture content of all the boards in the four packages was 23.7 percent, with the values ranging from 15 to 31 percent (table 1). The ranges in moisture contents for the various packages show that the values were fairly consistent. The average moisture contents for the individual packages were 20.8, 23.1, 26.7, and 25.1, respectively.

A summary of the moisture content and moisture distribution sections (A and B specimens), averaged by packages, is shown in table 2. These values show that the difference in percent moisture content between the shell and core was slight. This is as expected--the boards were newly sawed and had had no opportunity to dry. Likewise the difference in moisture content of the three specimens was slight. The greatest difference was 1.7 percent for package No. 3.

Table 1.--*Summary of the moisture meter values*[1] *for dimension lumber produced from [illegible]*

Package number	Size of boards	Number of boards	Moisture content of boards[2]		
			Minimum	Maximum	Average
			Percent		
1	2 by 4	204	15	30	20.8
2	2 by 4	204	16	30	23.1
3	2 by 4	192	18	31	26.7
4	2 by 6	128	18	28	25.1
All packages		728	15	31	23.7

[1]The moisture meter readings were corrected for temperature.
[2]The average of at least three moisture meter readings taken on each board was used for the moisture content of that board.

Table 2.--*Summary of actual moisture content (ovendry method) of test [illegible]*

Package number	Number of boards in subsample	Size	Average moisture content		
			A sections	B sections	
				Shell	Core
			Percent		
2	10	2 by 4	26.3	27.6	27.3
3	9	2 by 4	28.4	27.9	29.6
4	6	2 by 6	29.2	30.3	30.9

For package No. 2, the average moisture content derived from the ovendry test was 4.2 percent higher than the moisture meter average; 2.9 percent higher for package 3; and 5.8 percent higher for package 4. These increases might be attributed to the reduced reliability of moisture meter readings above 25 percent and the fact that the meter readings were not corrected for species (James 1975). A relationship between moisture values obtained from meter readings and the ovendry method is discussed under "Recommendations."

The drying stress sections indicated that only minor stresses were present. The prongs on 61 of these specimens remained straight, on 26 specimens there was a slight degree of casehardening (prongs turned inward) and on 6 specimens there was a slight reverse casehardening (prongs turned outward) (fig. 2). The turning of the prongs inward indicated that some tension set had developed and turning of the prongs outward would occur only when wood below 30 percent moisture content was rewet.

For green western white pine, the Wood Handbook (Forest Products Laboratory 1974) lists values of 62 and 148 percent moisture content for heartwood and sapwood, respectively. The average moisture content by oven test of our wettest test package is about half of the moisture content value for green heartwood; so a drying time about half as long should be expected. The low moisture content should also enable the wood to withstand a higher initial dry bulb temperature than could be used with green wood. With this more severe drying schedule, the initial wet bulb depression should be minima in order to reduce the development of drying stresses (McMillen 1968).

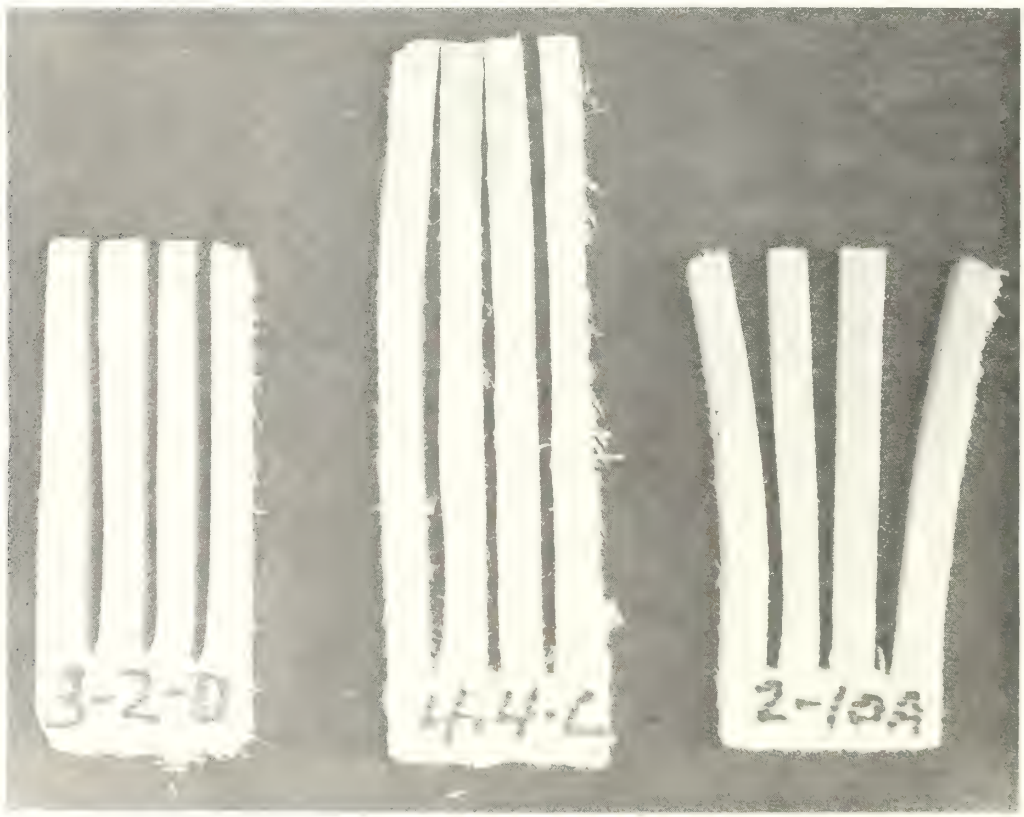

Figure 2.--Photo of typical drying stress sections obtained from boards in package No. 3, 4, and 2. The center figure shows casehardening; the figure on the right shows reverse casehardening.

For the mill that produces a quantity of dead lumber, some experimentation will probably be necessary to determine the optimum drying conditions. The white pine study mill was equipped with a high temperature kiln. The mill has settled on the practice of using an initial dry bulb temperature of 190° F with a wet bulb depression of 30° F. During the winter months when the logs and lumber are high in moisture content or are frozen, these drying conditions are maintained for 24 hours. During the summer months, and especially if there is a delay between piling and drying, the kiln time is reduced to 12 hours, but the same drying conditions are used. Whether these are optimum drying conditions is not known, but the mill reports no planer split or other drying degrade as a result of these schedules.

LODGEPOLE PINE

Methods

The second study, on lodgepole pine, was conducted at a mill in southeastern Idaho. This mill obtains most of its logs from the Targhee National Forest which has been the site of an epidemic infestation by the mountain pine beetle, *Dendroctonus ponderosae* (Hopk.). Over the past two decades, this insect has been responsible for killing an estimated 2 billion board feet of lodgepole pine timber on this Forest. Some of this dead timber has been purchased by the study mill.

The mill is equipped with a small headrig for breaking down logs over 14 inches in diameter and a quad-band mill for sawing logs under 14 inches. Edgers are used to cut the cants into 2 by 4's. Only studs and a few 1 by 4 sideboards are produced. This limited number of products eliminates the necessity for a green chain, instead the lumber is stickered and piled on kiln trucks for drying at the back end of the mill.

For this study a sufficient number of dead logs were processed through the mill to produce two kiln trucks of studs. The logs were debarked, cut to length, and fed into the mill. A measuring station was established at the midpoint of the chain carrying the studs to the stacker. At this station, the moisture content of a random sample of the studs was determined using the same moisture meter used in the earlier study. The speed of the chain and the desire to sample as many studs as possible precluded the use of all the meter scales; instead only the 12 to 22 percent moisture content scale was used. Those studs having a moisture content greater than 22 percent were recorded as having the scale maximum. In addition, 22 studs were pulled from the chain for destructive sampling. At the completion of the mill run a 2-foot-long piece was cut from the center of these studs and saved for later preparation of test sections.

Three test sections, approximately 1 inch long were cut from near the center of each piece as in the earlier study (fig. 1). These sections, again labeled A, B, and C, were used for determining moisture content, moisture distribution, and drying stress.

After determining their moisture content, the studs were piled for drying in the automatic stacker. The two kiln trucks of dead tree studs accumulated during the study were identified and dried in a single kiln charge along with six trucks of green studs.

The regular green drying schedule was used to dry the charge. This 98-hour schedule uses an initial dry-bulb temperature of 160° F, a final temperature of 180° F, and includes two 3-hour steaming periods. The initial wet-bulb depression was 10° F, and the final depression was 90° F.

After drying, the studs were surfaced and bundled for shipment. The moisture meter was used to obtain a sample of moisture readings as the studs were being packaged

Results and Discussion

The moisture content of slightly more than half of the studs (1,658 of about 3,050) cut from dead lodgepole pine logs was measured with a moisture meter in the sawmill. One reading was obtained from the approximate center of each piece. The average of these meter readings was 16.5 percent. However, the true value is probably somewhat higher than this value as 225 (approximately 14 percent) of the readings were above 20 percent and undoubtedly some of these values exceeded the maximum of the meter scale used. The readings were not corrected for temperature or species. The distribution of the readings is shown in figure 3.

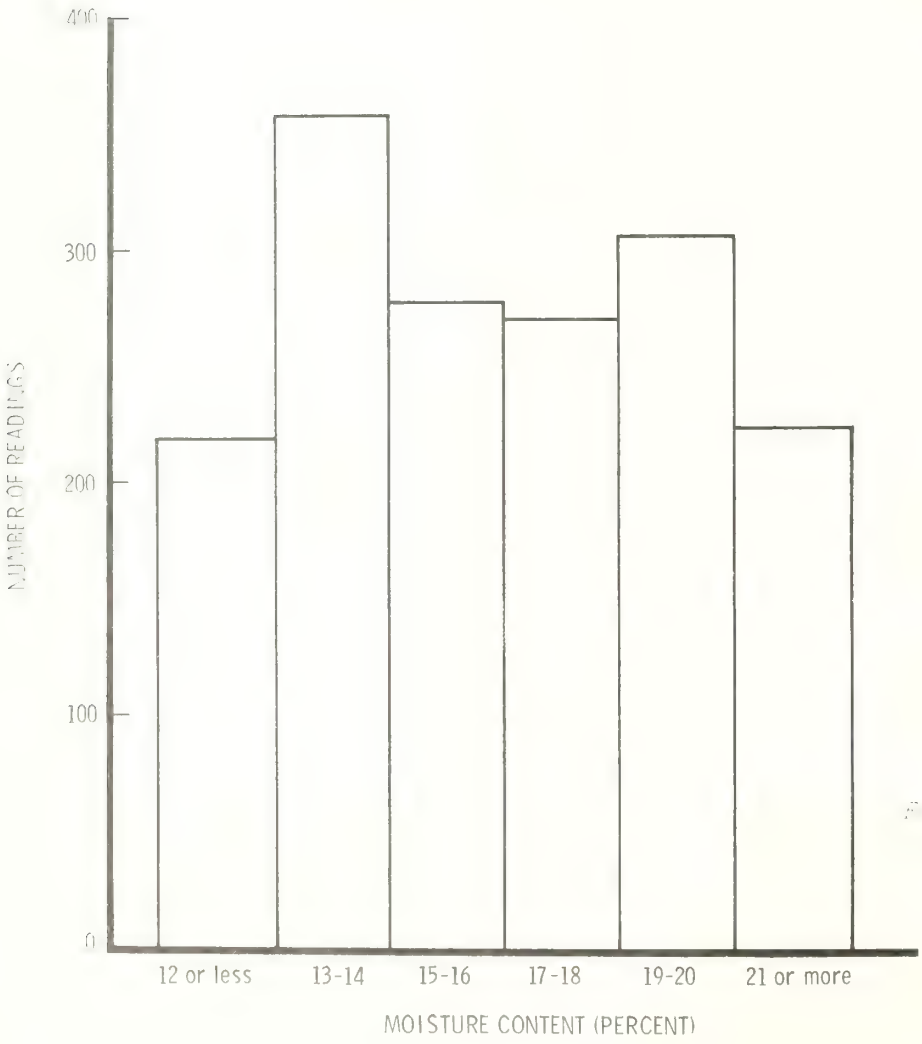

Figure 3.--Distribution of moisture content determinations made on lodgepole pine studs cut from dead trees.

1	16.7	16.7	16.5	16.6
			18.6	19.0
	17.0	18.1	17.1	
	16.8			
	25.1	25.5	26.3	24.9
	28.7	26.7	29.2	28.2
7	18.6			
	23.7			24.0
		28.4		31.2
10		18.2		
11		30.2		
12		39.6		11.1
		21.5	24.1	23.2
	19.1	19.4	19.7	
16	20.9		20.8	20.5
17	25.1			25.3
	18.7			
	24.5	25.2		24.5
		15.4		
21	25.0	22.0		25.0
		24.6		25.8
	25.1			

[1]Computed by multiplying the shell moisture content by 12, the core moisture
values was divided by 40.

The distribution of the moisture content of test sections A and B (moisture content and moisture distribution specimens) is shown in table 3. The average moisture content for the A sections was 23.1. The average for the shells of the B sections was 21.8; and for the cores 23.0.

Because of the variation in the lodgepole pine test sections and to obtain a reliable estimate of moisture content, a weighted average moisture content was computed. This value was calculated by multiplying the shell moisture content by 12, the core moisture content by 8, and the moisture content of section A by 20. The sum of these values was divided by 40 to obtain the weighted average moisture content. The computed values for the sample studs ranged from 15.3 to 41.1 percent and 12 of the 22 average values exceeded 20 percent (table 3). The maximum difference between the shell and core was 4.3 percent, and the average difference was 1.2 percent moisture content. Five of the shells had a slightly higher moisture content than the core. This is contrary to expectation and indicates some reabsorption of moisture.

Three of the 22 drying stress test sections showed a slight amount of casehardening or tension set. McMillen (1968) has shown that tension set develops from the start of drying and often reaches a maximum above 30 percent average moisture content. The

uniformity of moisture content and the lack of tension set indicate that any drying schedule for dead tree studs should not have too large an initial wet-bulb depression in order to minimize the development of drying stresses.

As before, the moisture content values obtained from the moisture meter were lower than those obtained from the ovendry tests. This discrepancy is probably due to the single meter scale used and the number of readings that exceeded the scale maximum. In general, the results of both the moisture meter readings and the ovendry determinations show that the moisture content of the studs is fairly uniform and less than 30 percent. This uniformly low moisture content indicates that the studs obtained from dead trees should dry in about half the time required for studs from green trees, which have an average heartwood moisture content of 41 percent and a sapwood moisture content of 120 percent (Forest Products Laboratory 1974).

After the dead tree studs had been dried and surfaced, the moisture content of a number of studs was remeasured with a moisture meter. The average moisture content of these studs was only 8.2 percent and the maximum value was 21 percent (fig. 4). A large percentage of the studs was in the 8 percent or lower moisture content class which suggests that when a small amount of dry material is included in a charge of green material, the final equilibrium moisture content should be about 6.5 percent. This would be especially desirable to avoid overdrying in wider boards subject to planer splitting.

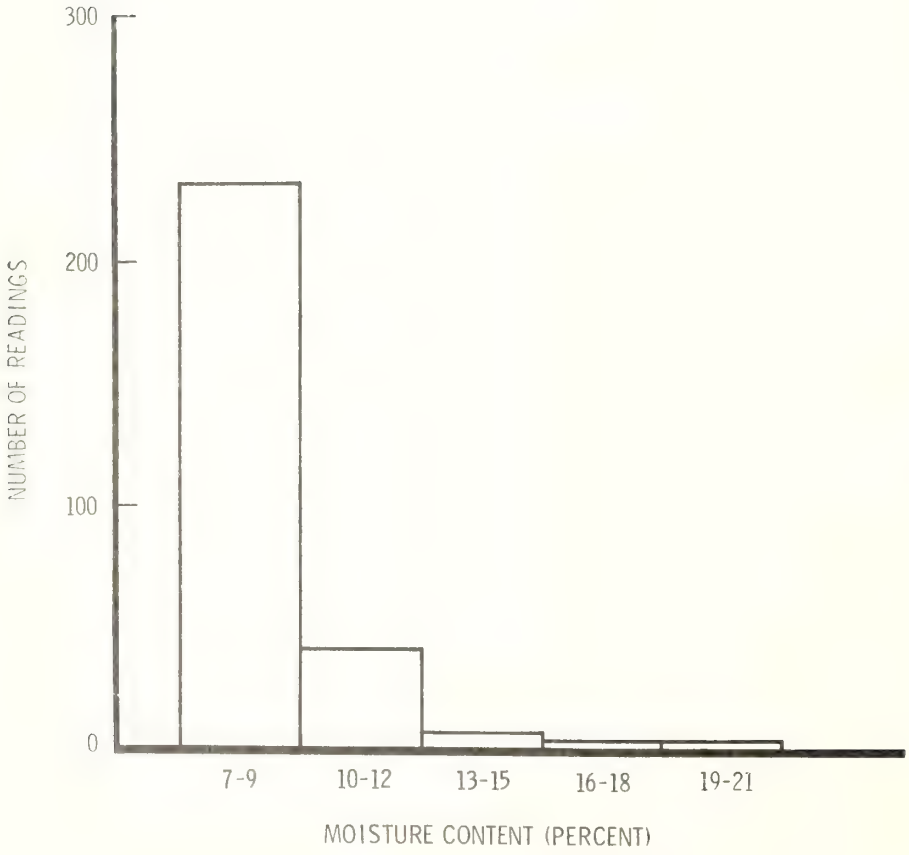

Figure 4.--Distribution of moisture content determinations made on kiln-dried lodgepole pine studs cut from dead trees.

CONCLUSIONS

These studies show that for both western white pine and lodgepole pine the moisture content of lumber made from dead trees is about half the moisture content of lumber cut from green trees. The average moisture meter reading obtained from four packages of western white pine dimension lumber was 23.7 percent, and the average moisture content obtained from a subsample of this material by the ovendry method was 28.8 percent. The average moisture meter reading for the lodgepole pine studs was 16.5 percent, and the weighted average moisture content based on ovendried test sections was 22.7 percent. The difference in the moisture meter readings and ovendry test results can be attributed to (1) the reduced reliability of moisture meter readings above 25 percent; (2) the fact that the meter readings were not always adjusted for temperature or species; and (3) the number of readings that exceeded the scale maximum in the lodgepole pine study but were recorded as the scale maximum.

The moisture distribution specimens showed there was only a slight moisture gradient in the dead tree lumber. The average difference between the shell and the core was less than 2 percent moisture content for both species. Also, neither the dead white pine nor the dead lodgepole pine lumber had any significant amount of drying stress. Out of 93 white pine test sections, 61 remained straight, 26 showed some casehardening, and 6 showed some reverse casehardening. Of the 22 lodgepole pine test sections, 19 remained straight, and 3 showed a small amount of casehardening.

As a result of the relatively low moisture content, absence of drying stresses, and low moisture gradient, the drying schedule used to dry lumber from dead trees should be about half the time required to dry green tree lumber. These schedules could use higher initial drying temperatures. Avoiding excessive drying will reduce energy costs as well as prevent degrading of material by overdrying.

RECOMMENDATIONS

It is impossible to make hard and fast rules for drying lumber from dead trees because of the variability in trees from different areas and in milling equipment and procedures. Furthermore, if only an occasional dead log is milled, the present practice of mixing the dead with green lumber and using the green lumber drying schedule is satisfactory. But if a sufficient quantity of dead lumber is produced to justify the sorting and use of a special drying schedule, greater efficiency will result. For the mill that does produce a quantity of dead lumber, some experimentation will probably be necessary to determine the optimum drying conditions. The study results reported in this paper indicate that the drying time could and should be reduced by at least 50 percent (based on the moisture content of the dead lumber).

We suggest that the kiln operator determine the initial average moisture content of a kiln charge by testing 20 to 50 boards, selected at random, with both moisture meter and the ovendry test method. These data can then be used to prepare a graph relating the moisture meter value to the oven test values (fig. 5). Thereafter, only moisture meter readings will be needed to determine the true average moisture content of the charge.

When a charge of dead lumber is ready to be kiln dried, the kiln operator should measure the moisture content of 50 to 100 boards in the charge with a moisture meter. Using the average of these readings he can determine the true average moisture content from the graph and then select the initial drying conditions by referring to the guides contained in the Dry Kiln Operator's Handbook (Rasmussen 1961) for that particular species, thickness, and grade of lumber. By taking postdrying moisture meter readings and evaluating the quality of the dried, surfaced lumber, the kiln operator can determine if any further changes in the drying schedule are desirable.

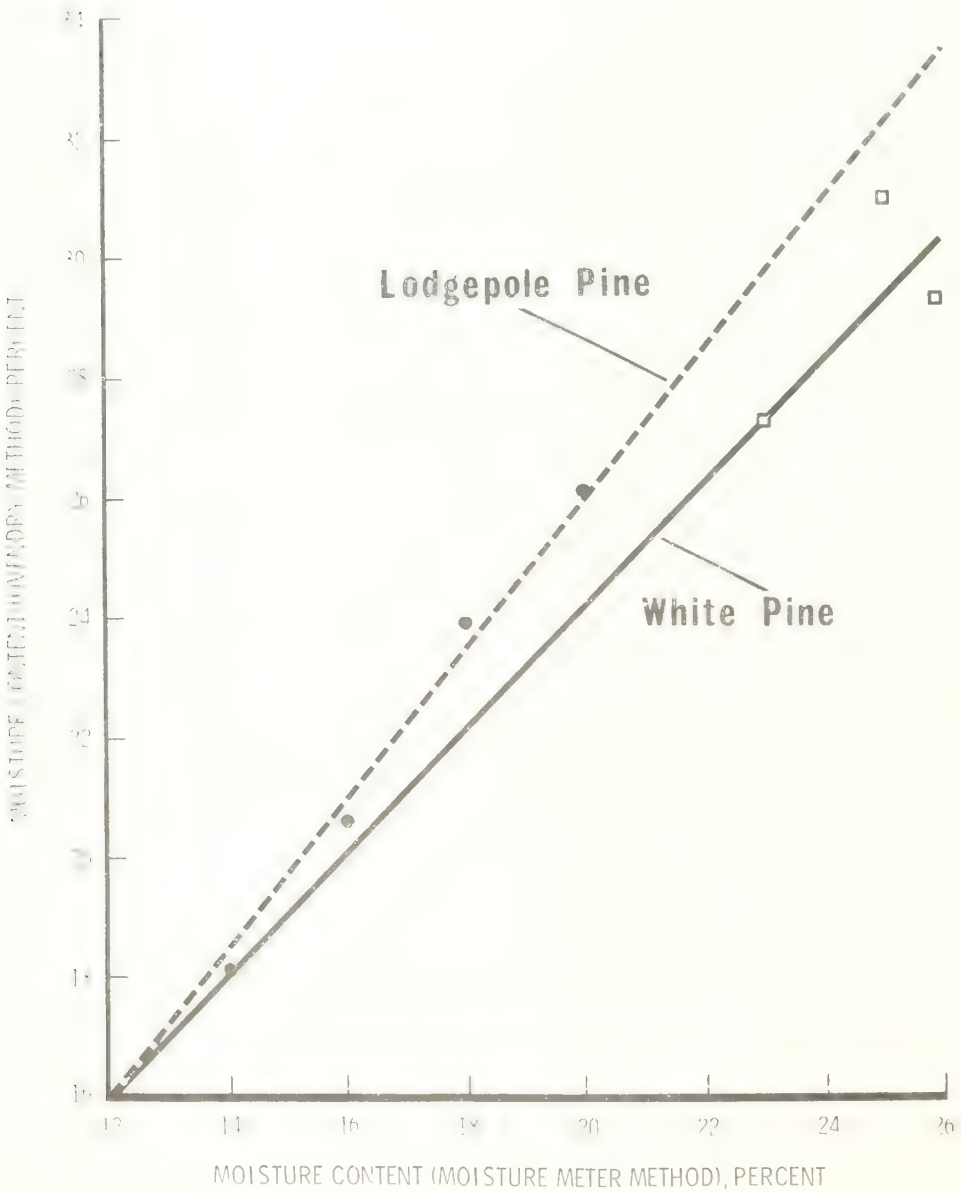

Figure 5.--Relationship between moisture meter readings and true moisture content as determined by ovendry method.

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Moisture content of lumber from dead western white pine and lodgepole pine trees was determined using both a moisture meter and the ovendry test method. For both species, the moisture content of lumber from dead trees was about half that reported for green lumber. The kiln drying time for lumber made from dead trees should be about half the time required to dry green lumber.

KEYWORDS: western white pine, lodgepole pine, dead trees, lumber moisture content, kiln drying schedule.

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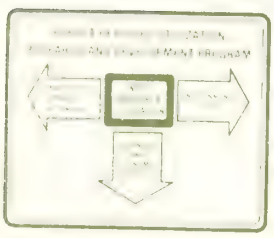

A HYDROLOGIC MODEL OF ASPEN-CONIFER SUCCESSION IN THE WESTERN UNITED STATES

Richard A. Jaynes

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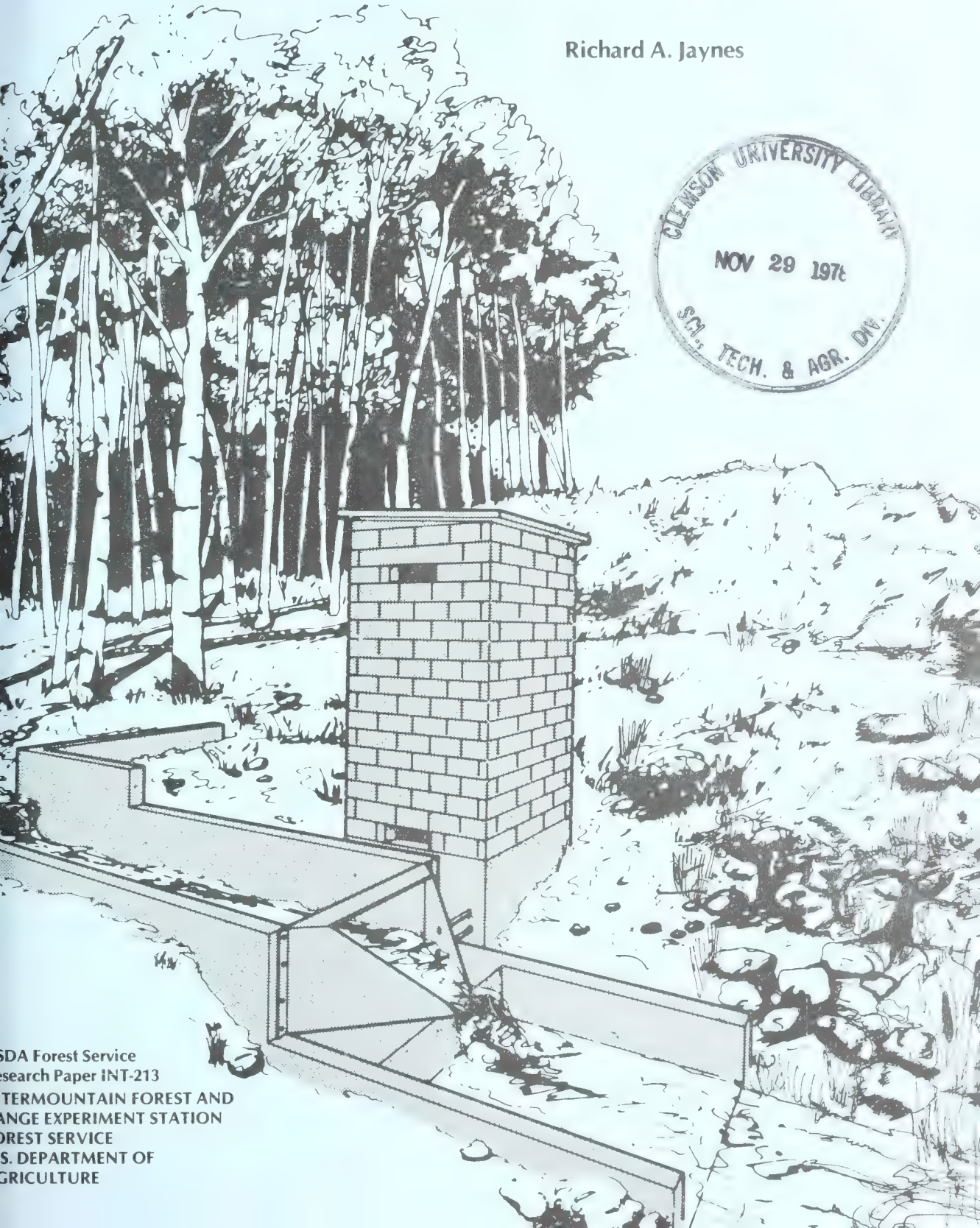

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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CONTENTS

	Page
INTRODUCTION	1
DEVELOPMENT OF ASPCON	2
TRANSFER FUNCTIONS	4
MODEL CALIBRATION	8
PREDICTED HYDROLOGIC IMPACT OF SUCCESSION	11
SUMMARY AND CONCLUSIONS	15
PUBLICATIONS CITED	15

RESEARCH SUMMARY

Hydrologic impacts of grass-forb to aspen to conifer succession in the Rocky Mountain area are simulated by means of a fundamental model. Model algorithms representing hydrologic processes are sensitive to vegetational changes within the subalpine vegetation zone. Reductions in water yield are predicted as the vegetation on a small Utah watershed proceeds from a grass-forb type to aspen to conifers. Streamflow changes are largely attributable to an interaction between seasonal consumption for each vegetation type and the influence of vegetation type on snowpack. The model synthesizes present understanding and provides a framework for future watershed research.

INTRODUCTION

Forests of quaking aspen (*Populus tremuloides* Michx.) are considered to be predominantly subclimax plant communities in the Rocky Mountain Region (Mueggler 1976; Bartos 1973). Mature aspen forests are most often replaced by evergreen conifers (*Abies* spp., *Picea* spp., *Pseudotsuga* spp., or *Pinus* spp.) unless some form of major disturbance occurs such as fire, disease, or clearcutting. When an overstory is thus destroyed, prolific root sprouting of aspen generally is initiated and aspen regains dominance on the site. In many areas where natural fires have been curtailed and logging has not occurred, former aspen stands are now dominated by coniferous species. More than 4.1 million acres of commercial aspen forests (Green and Setzer 1974), and possibly an additional 1.5 million acres of noncommercial aspen lands, exist in the Rocky Mountains. Resource managers are concerned that succession of sizable portions of these forests to conifers will have adverse impacts on the water, wildlife habitat, and livestock forage values of the aspen type.

Because water is a critical resource in the West, it is imperative that we accurately assess the impact that succession from aspen-to-conifer may have on water yield. The concept of ecosystem hydrology assumes complex interactions between the ecosystem and the hydrologic cycle, and that a change in one component should effect a change in the other (Huff 1971). With regard to transpiration, for example, Satterlund (1972) cited several studies that suggest "...the ecological principle that vegetation replacement by better-adapted species will continue until all favorable niches are occupied...." He concluded that "...it appears likely that maximum rates and amounts of transpiration during the drying cycle occur under climax vegetation."

It has been shown that western aspen may be expected to transpire 3 to 4 inches more water from a 6-foot soil profile than a grass-forb community on a comparable site (Johnston 1969). Douglass (1967) stated that many forest hydrologists believe well-stocked forests use the same amount of water regardless of tree species when end-of-season soil moisture deficits are examined. However, he pointed out that patterns of soil moisture depletion for hardwoods and for conifers are quite different. Because hardwoods begin transpiring later in the growing season than conifers, more water may drain through hardwood soil profiles early in the season. Thus equal soil moisture deficits under hardwoods and conifers may not represent equal amounts of transpiration. Urie (1967) studied the net ground water recharge under hardwood and conifer stands in Minnesota. He found that the net annual water yield to ground water reservoirs from hardwoods exceeded conifers by 2.6 inches. This difference was associated with a greater snowpack under hardwoods and a longer transpiration season for conifers. He found that when transpiration and ground water recharge were combined, the conifers consumed 5.7 inches more water than hardwoods on comparable sites.

In a Colorado study, Dunford and Niederhof (1944) concluded that, from the standpoint of net water available for streamflow, aspen is probably superior to conifers. A most meaningful insight to this problem was provided by Swank and Douglass (1974) who observed a 20 percent reduction in streamflow 25 years after a hardwood stand in North

Carolina was converted to pine. Such a study is needed in the West to more accurately define the actual changes in watershed hydrology where aspen-conifer succession is occurring. In the absence of such research, a watershed hydrologic model based on recognized hydrologic processes and utilizing appropriate data from past studies and modern computer technology may provide useful insights. Such a hydrologic model may be of particular value in identifying critical research needs.

A major purpose of hydrologic simulation modeling is to realistically and precisely represent a system (a series of processes) with a network of mathematical expressions (Riley and Hawkins 1975). Models are comprised of coefficients, structure and initial conditions that interact to manipulate each piece of input data to produce a desired output. Before a model can be deemed acceptable, it must be properly identified and formulated, calibrated to mimic observed system behavior, and verified through repeated testing. Simulation models integrate the effects of a variety of subprocesses in order to provide for maximum utilization of a given information base in terms of predictive capability of system performance (Riley and Hawkins 1975).

The purpose of this study is to formulate a structural watershed hydrologic model that will integrate available knowledge relevant to the hydrologic impacts of aspen to conifer succession. Although Leaf and Brink (1975) have written a rather sophisticated subalpine hydrology model, a fundamental model sensitive to aspects of the hydrologic cycle that may be influenced by vegetation changes would be useful. The model described in this report begins to satisfy that need.

DEVELOPMENT OF ASPCON

The model describing the hydrology of aspen to conifer succession (ASPCON) consists of a series of moisture storage compartments connected by transfer equations that systematically deal with each set of input data (fig. 1). As moisture enters and interacts with a watershed, a certain amount is lost to the atmosphere via evapotranspiration, while the remainder may become streamflow or percolate deep into the soil.

Obviously ASPCON can only be as valid as the assumptions that were made as the model was constructed. Literature pertaining to hydrologic behavior of grass-forb, aspen, and conifer ecosystems was carefully reviewed; only key references are cited. The model's transfer equations were derived from research findings that varied widely in location and purpose and, therefore, often were not directly applicable. Consequently, many water movement equations must be considered educated guesses. This lack of information points out the need for definitive research that directly relates to the critical hydrologic problems associated with aspen-conifer succession.

ASPCON is a deterministic, lumped-parameter model. The watershed is treated as a single series moisture storage "tank." Model coefficients related to watershed characteristics represent averaged values. The model calculates weekly water budgets throughout 1 water-year (Oct. 1 to Sept. 30). System input includes only precipitation and average weekly air temperature. The transfer functions for moisture routing within the watershed are described below in the sequence of ASPCON's algorithmic logic.

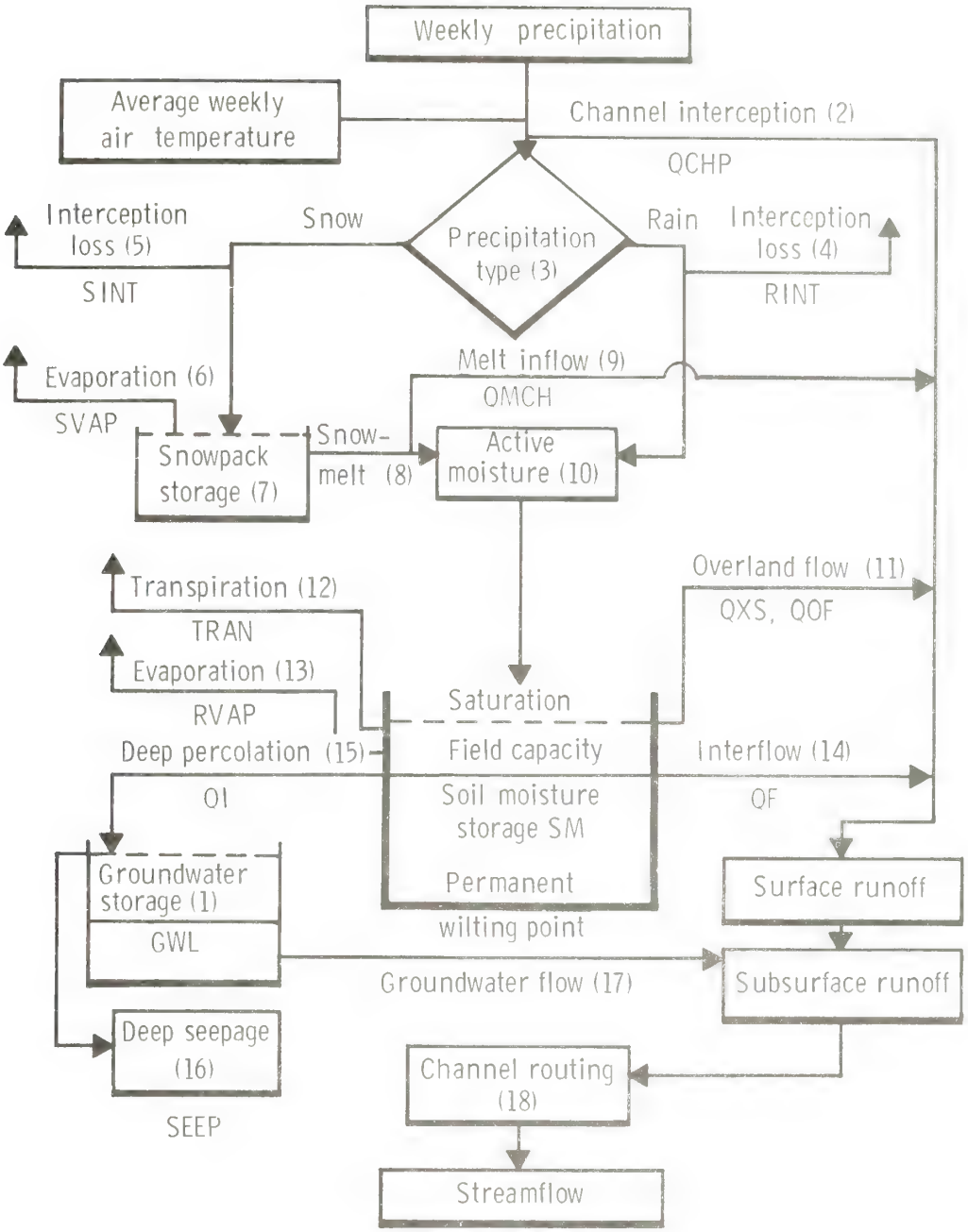


Figure 1.--Flowchart for the [illegible]. (Numbers in parentheses refer to definition given in text.)

TRANSFER FUNCTIONS[1]

1. Calculation of initial ground water level (GWL, in) from baseflow. At the beginning of the water-year (Oct. 1) average streamflow for the last rainless week of September is used to define the initial GWL. Initial GWL is the quotient of stream baseflow (in) divided by a ground water recession coefficient (AGW, in/in).

2. Channel interception (QCHP, in). The amount of moisture falling directly int the stream channel is defined as the fraction of the total watershed area consisting c surface water or saturated streambanks (ACHP, in/in) multiplied by the precipitation input. The value for ACHP may be determined from an areal map of a watershed.

3. Precipitation type. Form of precipitation is determined by using a routine similar to the model developed by the Army Corps of Engineers (1956):

$$\text{If } TEMP < TMIN,\ RP = 0.0$$
$$\text{If } TEMP > TMAX,\ RP = 1.0$$
$$\text{If } TMIN \leq TEMP \leq TMAX,$$
$$RP = (TEMP - TMIN)/(TMAX - TMIN)$$

where: TEMP is mean weekly air temperature (°F), TMIN is a critical minimum temperatu below which all precipitation is snow, TMAX is a critical maximum temperature, above which all precipitation is rain, and RP is the fraction of input moisture that falls as rain.

4. Rainfall interception loss (RINT, in). Vegetative canopies are known to inte cept and retain a fraction of rainfall that is ultimately evaporated back to the atmos phere. The amount of rainfall greatly influences the amount of net moisture (moisture entering the soil) for individual storms; estimates of yearly interception losses are follows: grass-forb, 9 percent; aspen, 12 percent; and conifer, 20 percent (Helvey 197 Johnston 1971; and Verry 1976). The fraction of moisture received as rainfall that ma be considered interception loss is assumed to be an average, weighted by areal cover o each vegetation type, of three rainfall interception storage coefficients (GSTR, ASTR, and CSTR, in/in).

5. Snowfall interception loss (SINT, in). Researchers have many different opinions about moisture loss from intercepted snow in coniferous canopies (Satterlund and Haupt 1970; Miller 1962). Estimates of the magnitude of such losses generally range between 6 and 10 percent of total snowfall (Anderson 1969). The amount of snowfall interception loss from leafless aspen is assumed to be relatively minor. The fraction of snowfall that becomes interception loss is defined in ASPCON simply as the weighted average of two interception loss coefficients, SNA (aspen) and SNG (conifer), with respective values of 0.01 and 0.07 in/in. The interception loss of snow by the grass-forb type is assumed to be zero.

[1] Numbers correspond to the items presented in figure 1.

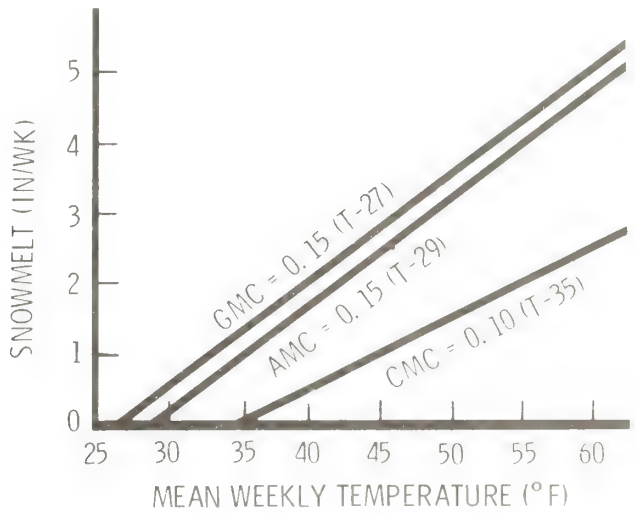
6. Snowpack evaporation (SVAP, in). Doty and Johnston (1969) found evapor
sses from snowpacks in winter as follows: open ground, 0.05 in/in, under a
/in, and under conifers, 0.026 in/in. A weighted average of three snowpac
ve loss coefficients, GSV, ASV, and CSV, is assumed to be the fraction of
at is evaporated during the year.

7. Snowpack accumulation. Research suggests that vegetati
owpack in western watersheds (Gary and Coltharp 1967; Th
ederhof 1944; and Meiman 1970). Accordingly, snowpack
fferently for each vegetative type. Snowpack accumulation
total net snowfall for each community type (99 percent in
nt in aspen areas, and 95 percent in conifer areas). Th
es provide for a redistribution of snowfall within the wate
th field observations.

8. Snowpack melt. Just as snowpack accumulation patterns vary betw
ver types, the timing and rate of snowmelt may also be expected to change as a fun
on of vegetative succession. Snowpack ablation may be expected to begin
en area and last in a coniferous forest. Snowmelt rates should be about the same
r open and aspen areas but significantly slower for coniferous types (Th
derer and others 1972). Snowmelt in ASPCON is indexed by mean weekly air temperature
a manner similar to the Army Corps of Engineers (1960) model. Figure 2 shows that,
r each vegetative type, the amount of snowmelt is a function of a melt rate coeffi
ent, GMC, AMC, and CMC (in/°F wk), and a base temperature coefficent, GBASE, ABASE,
d CBASE (°F), for grass-forb, aspen, and conifers, as well as mean weekly temperature
F).

9. Channel inflow from snowmelt (QMCH, in). Part of each increment of snowmelt
y be expected to occur on saturated soil adjacent to stream channels and, therefore,
readily enter the stream channel. The fraction of snowmelt thus contributing to
reamflow is equivalent to the product of the amount of snowmelt and a melt inflow
efficient (TMCH, in/in). TMCH functions similar to ACHP and may be estimated from
areal map of a watershed.

10. Active moisture input. The term "active moisture" is defined as the sum of
et weekly rainfall and snowmelt. Active moisture is capable of entry into the soil
ystem (depicted as the large "tank" in fig. 1) for subsequent evapotranspiration,
eep percolation, or direct contribution to streamflow.



igure 2.--Snowmelt functions for the grass-forb, aspen and conifer vegetation types.

11. Overland flow when infiltration rate is exceeded (QXS, QOF, in). The model provides for calculating overland runoff when active moisture input exceeds infiltrati capacity (FI, in/wk). This condition may occur when the soil is below saturation (QXS a rare occurrence on subalpine watersheds) or when the soil is saturated (QOF, which occurs primarily during the spring snowmelt season). Because the model is incremented on weekly intervals, QXS cannot be estimated accurately. Consequently, the infiltrati capacity is set at a sufficiently large value to preclude any QXS. The model may be set for any desired increment period, which could make QXS a more important hydrologic factor.

12. Transpiration (TRAN, in). The model treats evaporation of water via plant stomates (transpiration) and evaporation of moisture from the surface soil as two distinct processes. To reflect the differences between grass-forb, aspen, and conifer communities that are suspected to influence TRAN, the following relationship is assume

TRAN = f (potential evapotranspiration, seasonal plant activity, plant rooting depth, community crop coefficient).

a. Potential evapotranspiration (PET, in) is calculated according to the model described by Blaney and Criddle (1962).

b. Plant activity index (PAI). Although aspen and conifers have been shown to be comparable in terms of end-of-season soil profile moisture content (Brown and Thompson 1965), there is little direct research that describes relative year-round-consumption patterns. Several researchers have found that conifers may actively transpire water at times of the year when deciduous tree species are dormant (Swanson 1967; Owston and others 1972; Smith 1975; and Urie 1959). Accordingly, a plant activity index (PAI, fig. 3) is defined as that fraction of peak activity that a plant communit

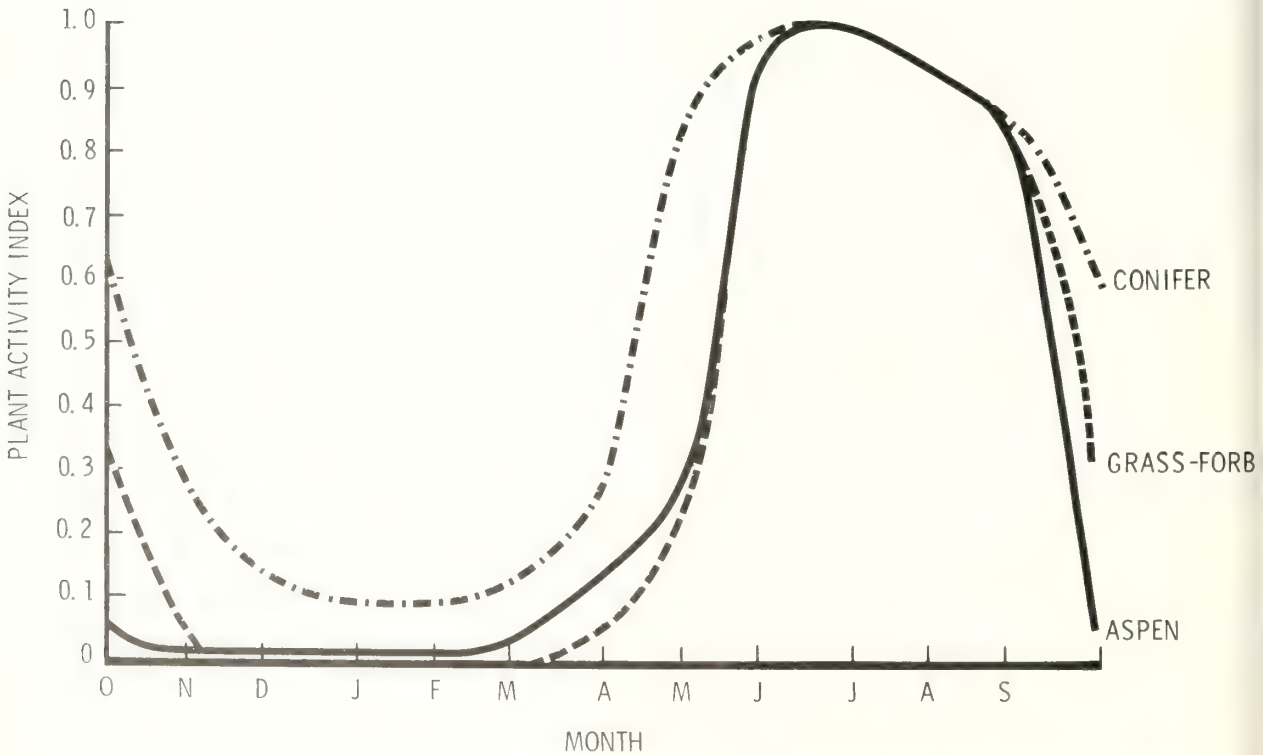
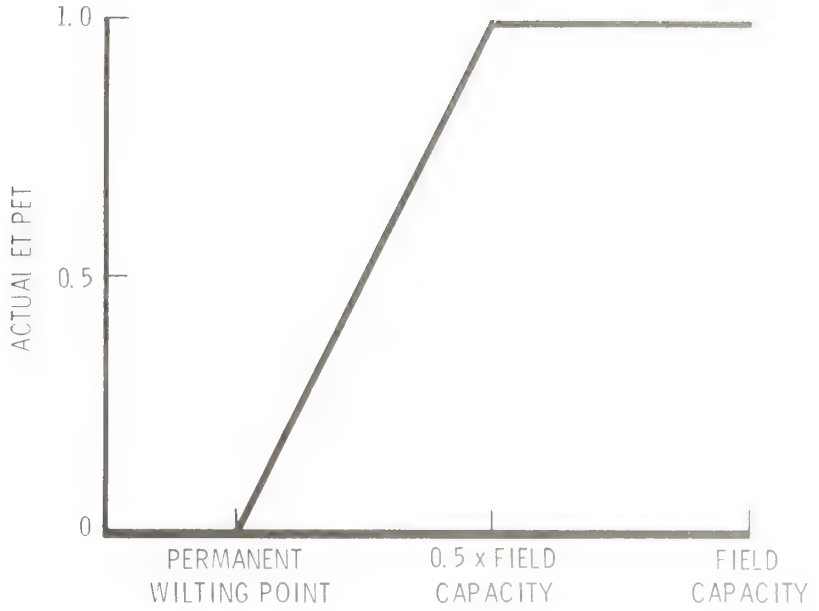


Figure 3.--Plant activity index for the grass-forb, aspen, and conifer types.

moisture on potential evapotranspiration.



ay reach when water is not limiting growth. The PAI is thus a [illegible] eek-to-week influence of day length and soil temperature on a plant's ability to ranspire water.

A correction is applied to PET to account for the effects of [illegible] n transpiration. The relationship outlined in figure 4 adjusts PET according to the ollowing rule: PET' = PET × (SM-PWP)/AWH where: SM is volumetric soil moisture content in), PWP is water content at permanent wilting point (in), and AWH is one-half of the rofile's available water or the difference between the water content at field capacity FC, in) and PWP. The adjustment of PET for limiting soil moisture is made according o a model by Hanks (1976), which is similar to the approach taken by Leaf and Brink 1975).

c. Plant rooting depth (RDP). The capacity of different plant communities to ccupy the root zone and the differences in mean soil depths for different watersheds re reflected in a plant rooting depth coefficient. The RDP is defined as that fraction f the total available rooting zone in the soil profile that contains 90 percent of all ive plant roots.

d. Community crop coefficient (CC). The crop coefficient is included in the model o reflect differences in consumptive use rates of water by different vegetation types hen all other factors are held constant. The grass-forb community is given the value f 0.9. Although forested communities may be expected to transpire greater amounts of ater than nonforested areas, it is questionable whether crop coefficients for aspen and oniferous forests should be different. Unlike coniferous forests, aspen forests gen rally have a highly productive understory which contributes to transpiration losses. owever, coniferous forests have a larger leaf area index and increased quantity of boveground biomass than do aspen forests. As a result of the [illegible] tions, the crop coefficients for aspen and conifer types are set at 1.25.

Watershed transpiration loss is weighted according to areal vegetation composition nd is calculated as the product of PET', PAI, RDP, and CC values.

13. Evaporation of rainfall from surface soil (RVAP, in). The model allows for a portion of rainfall to be evaporated from the surface soil. Generally in these forests, rain that falls during the growing season readily evaporates after each storm and seldom contributes to soil moisture recharge. A function was synthesized to reflect this phenomenon:

$$AK = RAIN/PET$$

If AK > 1, then AK is assigned the value of 1

$$RVAP = RAIN - (RAIN \cdot AK)$$

where: RAIN is net rainfall (in). The value of RVAP is then subtracted from the soil moisture content. As a consequence of defining RVAP as a function of rainfall amount as well as PET, significant amounts of rain are evaporated from the soil only during the growing season.

14. Soil profile interflow (QF, in). When soil moisture is above the water content for field capacity (FC, in), moisture may move laterally through the soil profile until it reaches the stream channel. Soil moisture in excess of field capacity is multiplied by an interflow coefficient (FQF, in/in) to define interflow.

15. Deep percolation (QI, in). The quantity of water that percolates through the soil profile and enters the ground water reservoir is calculated similar to QF except that a deep percolation coefficient (FK, in/in) is applied instead of FQF.

16. Deep seepage (SEEP, in). A portion of the water entering the watershed may leave the area without contributing to local streamflow. In other words, a fraction of moisture is routed via deep seepage into aquifers. The deep seepage storage compartment receives moisture when the ground water level reaches a certain maximum (TOP, in). When this maximum is reached, the ground water level is multiplied by a deep seepage coefficient (DPSP) to calculate the amount of water added to SEEP.

17. Subsurface flow from ground water storage (QGW, in). The amount of water entering the stream channel from the ground water reservoir is defined as the product of the ground water level and a ground water recession coefficient (AGW, in/in).

18. Channel routing of flow. Moisture for streamflow that is generated by the model may be expected to experience a timelag before passing through the gaging station at the mouth of the watershed. Therefore, the model provides for fractions of generated runoff to be delayed up to 5 weeks.

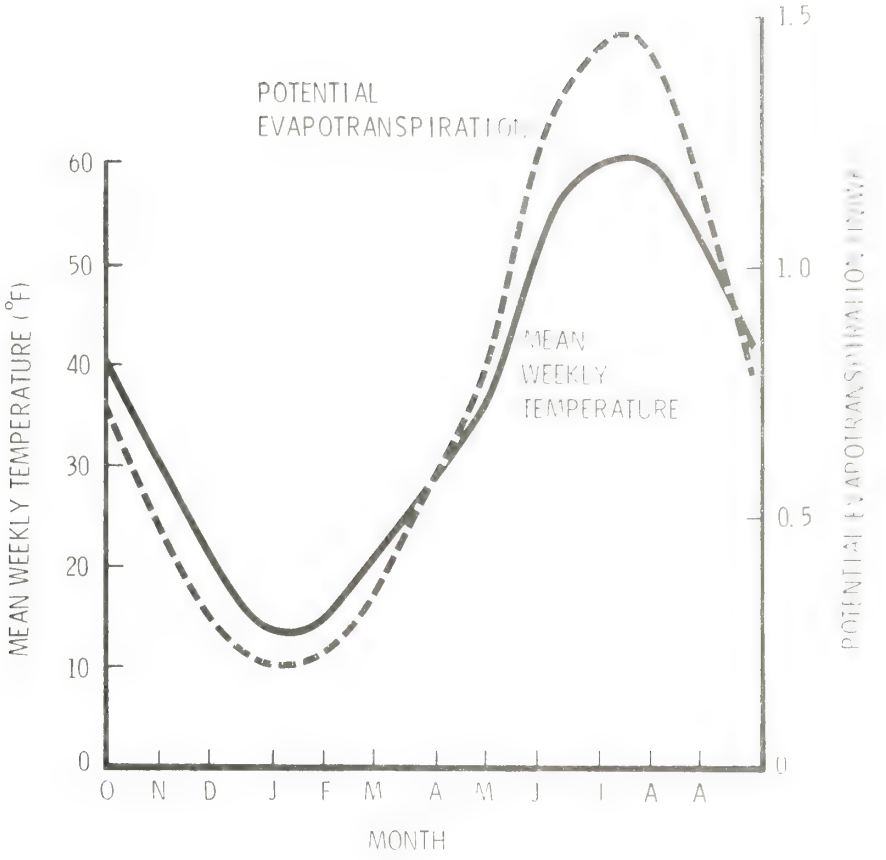
ASPCON computes weekly and yearly water budgets by summing all components of streamflow, evapotranspiration, and changes in soil moisture and ground water storage.

MODEL CALIBRATION

The model was calibrated for an "average" water-year on the West Branch Chicken Creek Watershed (CCW), Davis County Experimental Watershed in Utah. The present vegetation status on the 217-acre CCW is approximately 20 percent grass-forb, 78 percent aspen, and 2 percent conifer (Johnston and Doty 1972). A total of 47 inches of precipitation fell during the modeled year, of which 11.6 inches was rain and 35.4 inches was

temperatures and

Watershed.



snow. Average soil profile depths to limiting horizons were assumed to [illegible] feet. [illegible] age weekly temperatures and potential evapotranspiration fluctuated according to the patterns shown in figure 5. A series of annual hydrographs for observed CCW streamflow were analyzed and the model coefficients in table 1 were adjusted until a predicted hydrograph was produced that agreed closely with past watershed behavior. During the calibration process, the only coefficients to be adjusted were those coefficients not easily estimated from a knowledge of watershed characteristics but to which the model is sensitive. Table 2 presents the values for model coefficients [illegible] best available knowledge from the literature. The purpose of this calibration procedure is not to model CCW, but to develop a reasonable point of reference [illegible] hydrologic changes attributable to vegetation changes may be estimated.

Once an acceptable hydrograph was obtained, all coefficients except the vegetative cover parameters were held constant throughout the remainder of the study. Thereafter, the areal cover of vegetative types on the watershed (CVG, CVA, and CVC, table 2) was sequentially altered to simulate the entire grass-forb to aspen to conifer sere. Watershed response to relatively wet and dry years was examined for five different vegetative combinations by increasing or decreasing the amount of annual precipitation. Input: wet year = 58.8 in (125 percent of normal), dry year = 35.3 in (75 percent of normal), and drought year = 23.5 in (50 percent of normal).

Table 1.--*Model coefficients manipulated during calibration*

Symbol	Definition	Units	Simulation value
SMO	Soil moisture of a 5-ft profile at beginning of water-year	in	13.5
SAT	Soil moisture of a 5-ft profile at saturation	in	24.0
FC	Soil moisture of a 5-ft profile at field capacity	in	21.0
PWP	Soil moisture of a 5-ft profile at permanent wilting point	in	10.0
FQF	Fraction of soil water (SM>FC) becoming interflow	in/in	.95
FK	Fraction of soil water (SM>FC) becoming deep percolation	in/in	.63
AGW	Groundwater reservoir recession fraction	in/in	.0012
DPSP	Deep seepage to aquifers from ground water fraction	in/in	.01
TOP	Maximum ground water level	in	28.5
CRC	Channel routing coefficients	in/in	.5, .3, .1, .1
GBASE	Snowmelt initiation temperature for the grass-forb types	°F	22.0
ABASE	Snowmelt initiation temperature for the aspen type	°F	24.0
CBASE	Snowmelt initiation temperature for the conifers type	°F	30.0
GMC	Melt rate index for the grass-forb type	in/°F wk	.25
AMC	Melt rate index for the aspen type	in/°F wk	.25
CMC	Melt rate index for the conifer type	in/°F wk	.20
TMAX	Critical maximum temperature for precipitation	°F	34.0
TMIN	Critical minimum temperature for precipitation	°F	42.0

Table 2.--*Model coefficients held constant during calibration*

Symbol	Definition	Units	Assumed value
FI	Infiltration rate	in/wk	10.0
ACHP	Fraction of precipitation intercepted by the stream channel	in/in	.0065
TMCH	Fraction of snowmelt readily entering stream channel	in/in	.0085
GSTR	Vegetation storage of rainfall for the grass-forb type	in/in	.09
ASTR	Vegetation storage of rainfall for the aspen type	in/in	.12
CSTR	Vegetation storage of rainfall for the conifer type	in/in	.20
SNA	Snowfall interception loss fraction for aspen	in/in	.01
SNC	Snowfall interception loss fraction for conifers	in/in	.07
GSV	Snowpack evaporation fraction for grass-forb	in/in	.05
ASV	Snowpack evaporation fraction for aspen	in/in	.034
CSV	Snowpack evaporation fraction for conifers	in/in	.026
ACCG	Snowpack accumulation factor for grass-forb	in/in	.99
ACCA	Snowpack accumulation factor for aspen	in/in	1.06
ACCC	Snowpack accumulation factor for conifers	in/in	.95
CCG	Crop coefficient for the grass-forb type		.90
CCA	Crop coefficient for the aspen type		1.25
CCC	Crop coefficient for the conifer type		1.25
DPG	Rooting depth coefficient for the grass-forb type		.45
DPA	Rooting depth coefficient for the aspen type		.85
DPC	Rooting depth coefficient for the conifer type		.80
CVG	Fractional area of watershed occupied by grass-forb		.20
CVA	Fractional area of watershed occupied by aspen		.78
CVC	Fractional area of watershed occupied by conifers		.02

PREDICTED HYDROLOGIC IMPACT OF SUCCESSION

Predicted weekly water budgets for the CCW were found to reflect complex interactions among assumed hydrologic processes. For example, the upper portion of figure 6 illustrates when rain and snow were received on the watershed, the lower portion of the figure shows how vegetation affects the timing of moisture entry into the soil. The timing and amount of active moisture input is a function of snowpack melt rates and

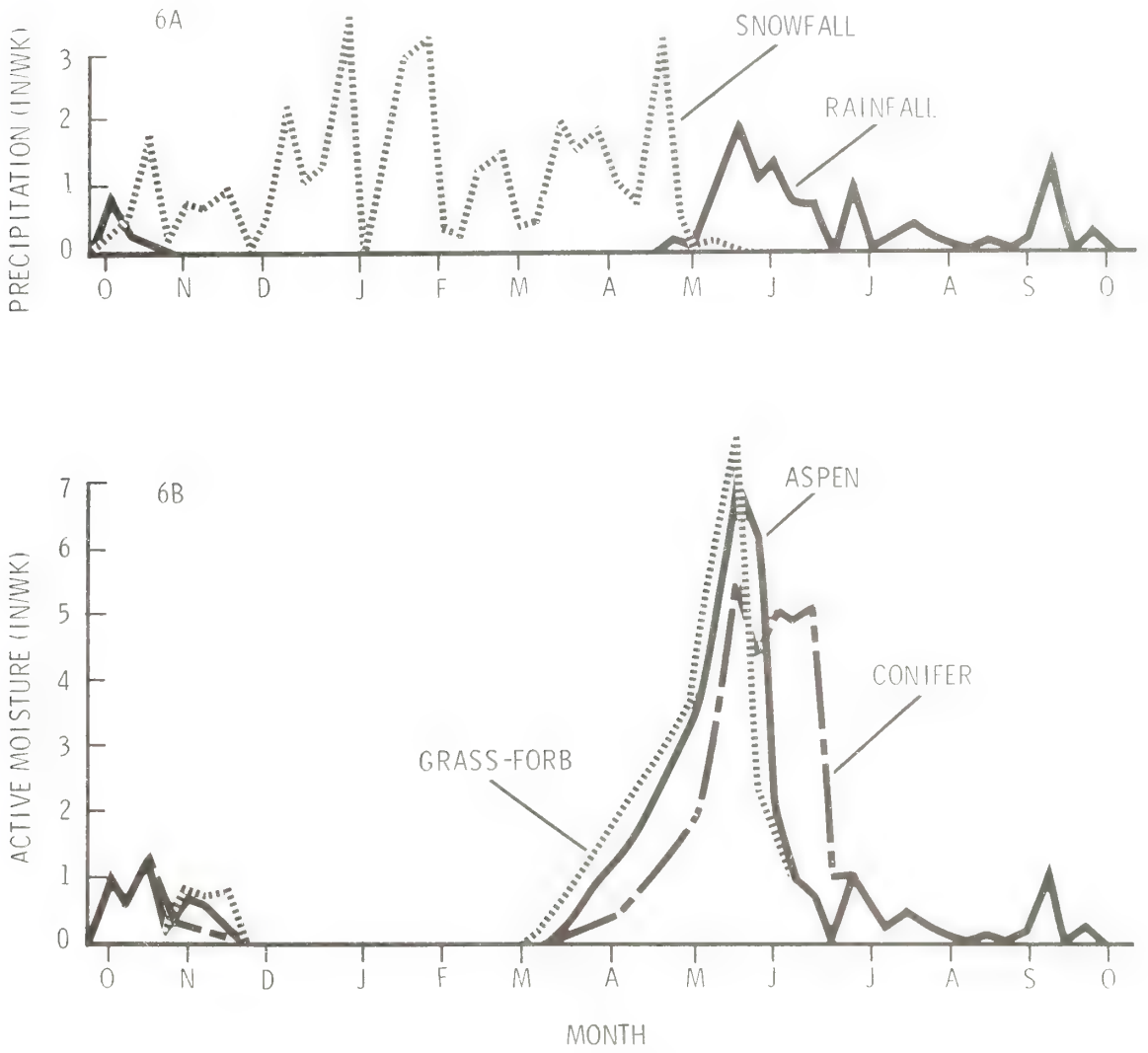


Figure 6.--Precipitation and active moisture input for the Chicken Creek Watershed.

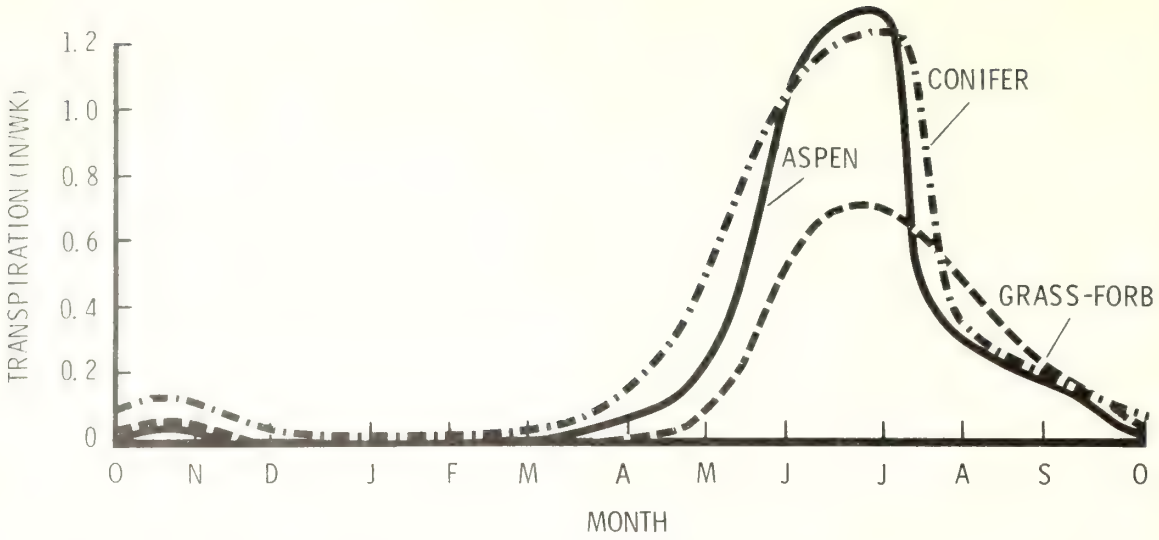


Figure 7.--Weekly transpiration patterns for the Chicken Creek Watershed when dominated by: grass-forb, aspen, and conifers.

evaporative losses (interception and soil moisture evaporation). Figure 7 presents the patterns of consumptive water use when the watershed is dominated by grass-forb, aspen, and conifer types. Greater consumptive use rates for conifer-dominated conditions may be attributed to the plant activity patterns of evergreen canopies. The combined effects of active moisture input, transpiration, and other components of the hydrologic cycle are reflected in the hydrographs in figure 8. Although the timing and magnitude of runoff under different types of vegetation cover vary substantially during the melt season, streamflow before and after the melt season is similar for all types. Dominance of aspen on a formerly grass-forb watershed causes spring runoff to be delayed slightly with lower peak flows. Spring runoff under conifer-dominated conditions is even further delayed and reduced.

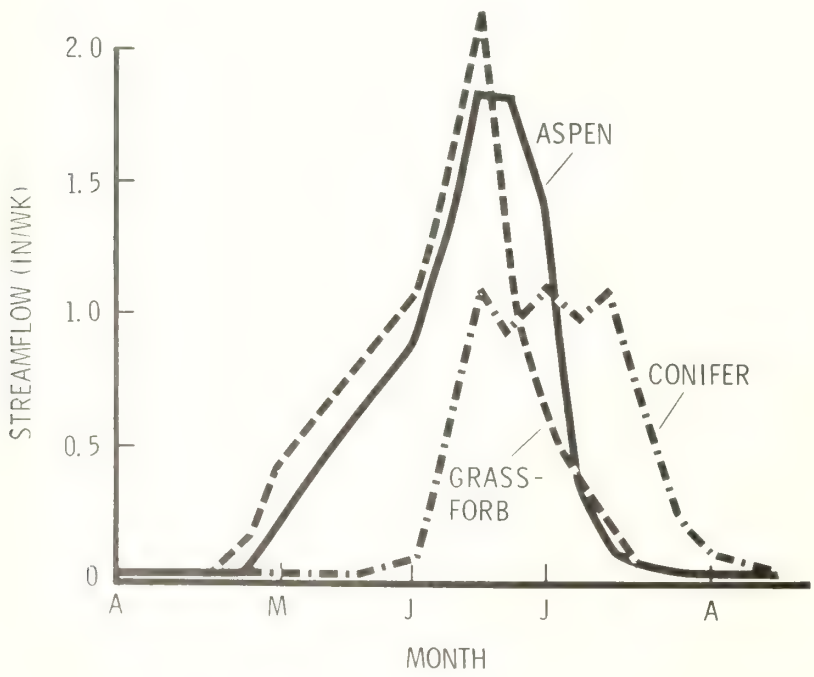


Figure 8.--Spring runoff hydrographs for the Chicken Creek Watershed when dominated by: grass-forb, aspen, and conifers.

Table 3.

Vegetation[1] status	Streamflow	Streamflow + ΔSM	Runoff[2]								
98-1-1	21.3					2.0		6.9			
90-9-1	21.3		48.7	3.1						1.1	
80-19-1	20.9		47.9			1.6				1.1	1.6
70-29-1	20.6			2.8		1.5			11.1	1.1	
60-39-1	20.3		45.5			1.1		6.6	11.7	1.2	1.5
50-49-1	20.3		44.7					6.6			1.5
40-59-1	20.2		43.0	2.4	15.4				12.7		1.4
30-68-2	20.0		42.6	2.3			1.8				1.3
20-78-2	19.9		42.3	2.6	15.0		1.7	6.5	13.1		
20-68-12	18.2		38.7	1.8	14.2	.0	1.7			1.4	
20-58-22	16.9	17.0	36.2	1.2		.1	1.6			1.5	1.2
20-47-33	16.3		35.1				1.8			1.6	1.2
20-36-44	16.1	16.0	34.6	.7	13.1	- .1	1.7				1.1
20-25-55	15.	16.1	34.3	.8	12.8	.3	1.8		16.	1.8	1.1
20-15-65	15.	15.	33.	.2	12.9		1.6		17.	1.9	1.1
20-5-75	15.	15.	32.6	.1	12.		1.8			2.0	1.0

[1]Percent watershed areal cover composed of grass-forb, aspen, and conifer types, respectively.
[2]Runoff percent is equal to (Streamflow + SM)/precipitation.
[3]See figure 1 for an identification of alphabetic codes.
[4]ΔSM and ΔGWL represent the net annual change in soil moisture and ground water level, respectively

Predicted annual water budgets for the "average" year for different combinations of vegetation types are given in table 3. In the CCW test area, the principal [illegible] following burning or clearcutting is visualized as less than 1 year's [illegible] grass-forb type, which is quickly followed by aspen dominance, which in turn is progressively replaced by conifers. Approximately 20 percent of the [illegible] grass-forb climax, and thus stabilizes at this level. Each [illegible] a position assumed for the watershed on the grass-forb to conifer sere. The length of the sere is not specified, since this may vary widely from site to site. The value for QCHP is a constant value (0.314 in) for all conditions. The values for QMCH, QGW, and RVAP exhibited the following minor trends from beginning to end of the sere: 0.29 to 0.28 in for QMCH, 1.77 to 1.71 in for QGW, and 2.66 to 2.87 in for RVAP. Several components of the water budget (TRAN, RINT, SINT, and SVAP) exhibited rather consistent trends along the sere. The other values in table 3 reflect the interaction of vegetation change with the timing and amount of moisture input and moisture loss due to evapotranspiration. The value for streamflow plus soil moisture change is presented since net change from the initial soil moisture at the end of the [illegible] will affect the following year's runoff (the soil storage compartment must be [illegible] runoff season). The amount of streamflow reduction plus the change [illegible] different stages of succession are illustrated in figure [illegible]. In the [illegible] the watershed, a net reduction in water available for streamflow of 5.1 in [illegible]. As the watershed proceeds from aspen to climax conifer [illegible], an additional [illegible] in is lost.

Annual streamflow under a variety of precipitation conditions was found to vary substantially along the successional gradient (table 4). Variable precipitation appears to alter the efficiency with which the watershed generates runoff: decreased runoff efficiency accompanies years of below-average precipitation. Late seral stages (conifer dominance) accentuate the reductions in streamflow for relatively dry years.

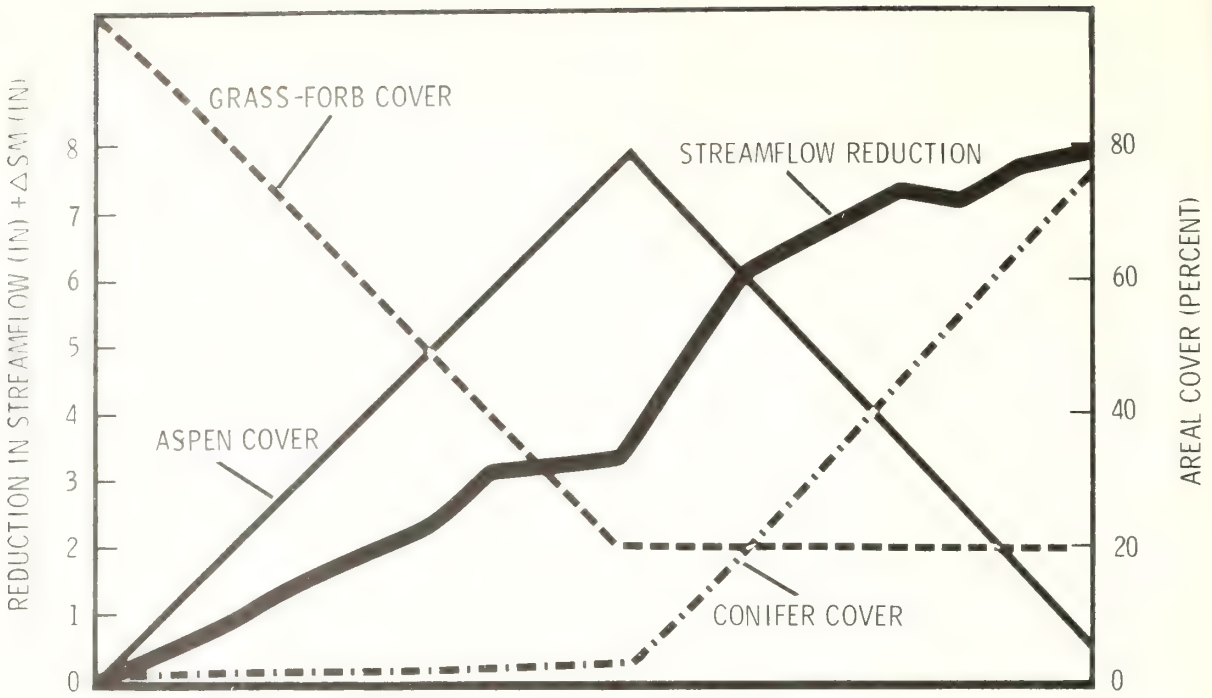


Figure 9.--Streamflow reduction +ΔSM for the Chicken Creek Watershed as a function of succession.

Table 4.--*Relationship of variable yearly precipitation to runoff (in) on the Chicken Creek Watershed*

Vegetation status[1]	Drought year	Dry year	Avg. year	Wet year
	Inches			
98-1-1	8.5	16.1	21.3	33.5
60-39-1	8.1	15.4	20.3	32.7
20-78-2	7.7	15.3	19.9	31.7
20-47-33	6.0	12.5	16.5	27.5
20-5-75	4.8	10.8	15.2	24.6

[1]Percent watershed areal cover composed of grass-forb, aspen, and conifer types, respectively.

SUMMARY AND CONCLUSIONS

A fundamental watershed hydrology model (ASPCON) has been developed that is sensitive to the vegetative changes associated with grass-forb to [illegible] succession that occurs on many subalpine watersheds in the Rocky Mountains. It represents a system of hydrologic processes that are likely to result in significant reductions in water yield for many western watersheds. The algorithms incorporated into the model were assumed from a current understanding of these hydrologic processes and a review of literature.

When applied to an actual watershed situation, ASPCON predicts a 3.4 in net loss of moisture available for streamflow when aspen dominate a former grass-forb watershed. An additional 4.6 in is lost when conifers eventually replace aspen forests on the watershed. The predicted reduction in streamflow between a predominantly grass-forb type and an aspen type is mainly a product of greater consumptive use of water and increased rooting depth of aspen. The reduction in streamflow as aspen are invaded by conifers is mainly a result of different snowmelt and plant activity patterns.

The predictive ability of ASPCON is a function of the validity of many assumed relationships. Research is urgently needed to more accurately establish the hydrologic changes attributable to aspen to conifer succession. ASPCON provides a framework capable of incorporating new information.

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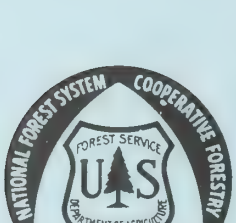
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FUEL BURNING RATES OF DOWNWARD VERSUS HORIZONTALLY SPREADING FIRES

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CONTENTS

Page

INTRODUCTION 1

EXPERIMENTAL PROCEDURE 4

RESULTS 5

DISCUSSION 6

PUBLICATIONS CITED 8

APPENDIX 9

Appendix A--Terms 10
Appendix B--Derivation of Maximum Load-Loss Rate . . 11
Appendix C--Statistical Test 12

RESEARCH SUMMARY

Maximum load-loss rate within the combustion zone of a vertically (downward) spreading fire was obtained for excelsior (0.07 cm in cross-section) at bulk densities from 0.0016 to 0.026 g/cm^3. Fuel was contained within a continuously weighed circular wire mesh basket 1 ft^2 (929 cm^2) in circular area and 0.5 ft (15.2 cm) deep, surrounded by a separate annular basket of fuel, to minimize edge effects. Load-loss rates were similar to those obtained by Rothermel (1972) for horizontally spreading fires in the same fuel at the same bulk densities.

The peak rate of load loss per unit area exhibits a strong dependence upon bulk density for both vertically and horizontally spreading fires. The maximum of this peak rate occurs at the same bulk density in the two cases. Because of these similarities, this method offers an alternative for investigating the combustion dynamics of fire; moreover, the vertical array is much easier to use than the horizontal array.

INTRODUCTION

Frandsen and Rothermel (1972) have presented a method of measuring the energy-lease rate of a spreading fire through the load-loss rate of a section of the fuel d. This paper describes an alternative fuel bed that uses less fuel, that takes less me to construct, and that is less complex to measure than the fuel bed used previ-sly. Fuel arrays to be examined are contained within a circular basket. The top is hited uniformly over the surface and the basket's fuel load loss is continuously corded as the fire moves vertically downward.

Rothermel (1972) has shown that the fundamental dynamics of fire spreading through porous fuel array can be expressed through Γ, the reaction velocity, the ratio of the ficiency of mass degradation during pyrolysis to the elapsed time of pyrolysis exper-nced during fire spread. Its product with w_n, the net original ovendry load of a fuel d, is equivalent to $\dot{w}$, the maximum load-loss rate of a portion of the fuel bed as the re spreads through the fuel:

$$\dot{w} = w_n \Gamma$$

e method of obtaining $\dot{w}$ experimentally has been covered by Frandsen and Rothermel 972) in their investigation of the reaction intensity of the combustion zone of a reading fire. (The rate $\dot{w}$ is properly a loss; however, the negative sense is inter-lly compensated.) The reaction intensity, I_R, is another important dynamic parameter the fire. It is the total energy-release rate evolved from the combustion zone, and related to $\dot{w}$ through h, the low heat of combustion:

$$I_R = h\dot{w} = hw_n \Gamma$$

e load-loss rate, $\dot{w}$, is an important basic parameter that relates to the dynamics of spreading fire. The maximum load-loss rate of a burning fuel array can be obtained monitoring the load of a basket of fuel as the fire moves with a horizontal plane wnward through the basket (fig. 1). The purpose of this paper is to show that, for celsior, the fuel basket experiences a maximum load-loss rate similar to that expe-enced by a horizontal fuel bed slice Δx, (fig. 2) at the same packing ratio, the tio of the bulk density to the particle density. Although the bed fire travels rizontally, the observer at Δx views a downward moving front that is similar to the ont illustrated in figure 1; namely, as Δx tends to zero, the boundaries of the pyrol-is zone can be easily approximated as horizontal planes. Because only the fuel slice weighed, the rate of change of the load within the slice is hypothesized to be entical to the rate of change of the load in the burning basket.

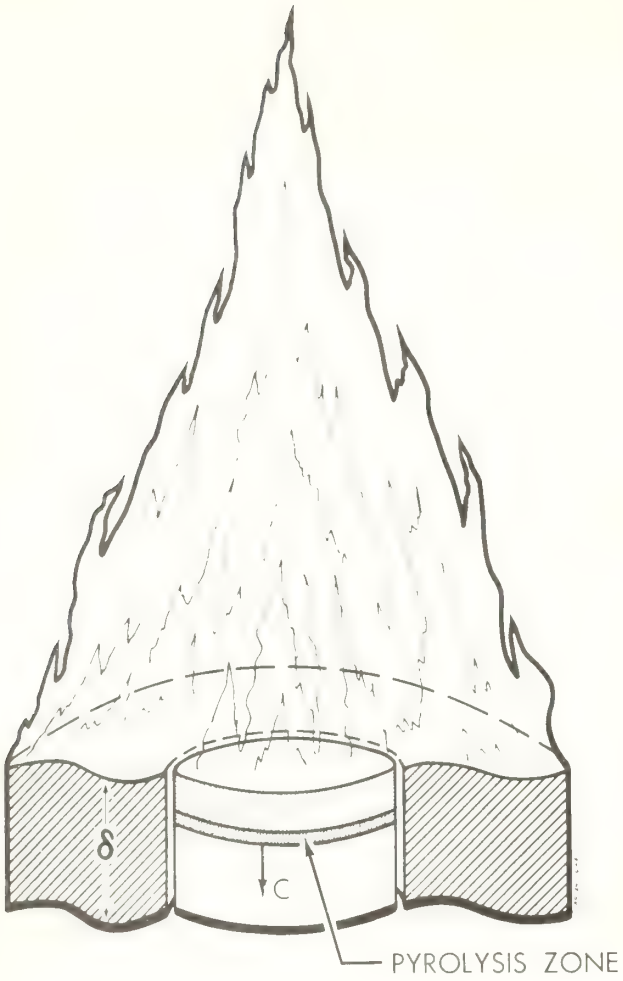

Figure 1.--A horizontal pyroly zone moving downward at a ra C, through a weighed fuel ba of depth, δ. A doughnut-sha basket surrounds the weighed basket to eliminate edge eff

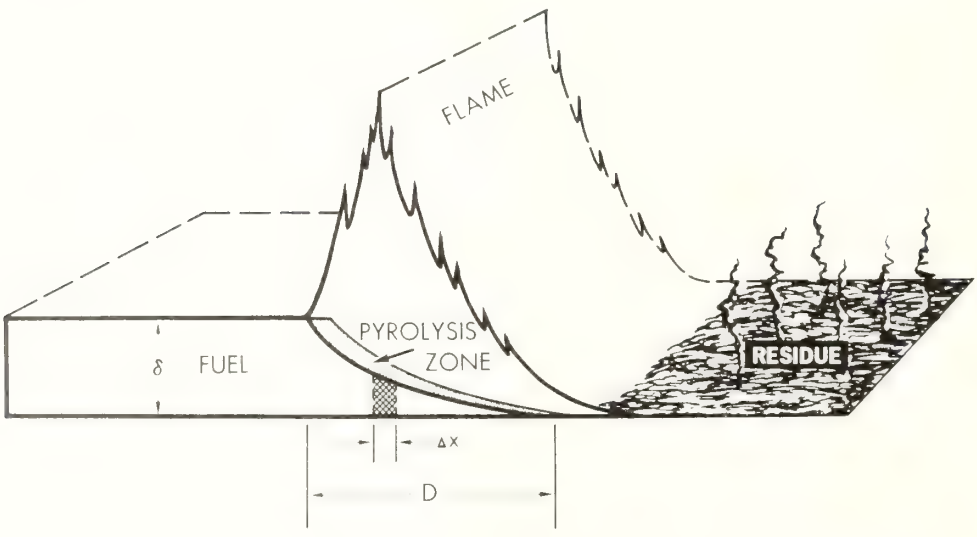

Figure 2.--A cross-sectional view of a fire spreading horizontally through a fine fuel (complete burnout). A weighed fuel slice is illustrated by Δx. The lower boundary of the pyrolysis zone is the ignition interface with the fuel.

EXPERIMENTAL PROCEDURE

The experiment was conducted in the combustion chamber of the [illegible] laboratory. The combustion chamber is connected to an environmental conditioning facility capable of maintaining humidity within ±1.5 percent and temperature within [illegible] (±0.5° C). The entire series of experimental burns was run at 80° F (27° C) and 20 percent relative humidity, resulting in a 5 percent equilibrium moisture content for the fuel. The burns were conducted under an exhaust flue in the center of the combustion chamber 44 by 44 by 66 ft (13.4 by 13.4 by 20.1 m.)

A wire mesh basket (13 by 13 mm grid mesh size), 1 ft^2 (929 cm^2) in circular area and 0.5 ft (15.2 cm) deep was used to contain the fuel. Square cut aspen wood excelsior (*Populus tremuloides* Michx.), 0.07 cm in cross-sectional dimension (a fine fuel) was used; the same fuel was used in the original spreading fire experiment to which the burning basket results are to be compared. The particle density was 0.40 g/cm^3. Different packing ratios were obtained by changing the load while holding the depth fixed. A doughnut-shaped basket with an annular space of 0.5 ft (15.2 cm) and identical depth and packing ratio surrounded the inner basket (fig. 1) to eliminate edge effects and thus maintain a horizontal planar combustion front as the fire moves downward through the inner basket. Separation between the baskets is highly important. An annular space of one-fourth inch (0.6 cm) separating the inner and outer baskets was optimum for these tests. A larger space will result in increased burning within the open annular space deteriorating the horizontal combustion front, whereas a smaller space will result in serious disturbance to the load measurement through connecting bridges occasioned by heat warping the adjacent wire mesh walls of the baskets.

A string presoaked in xylene, a highly flammable fluid, was laid back and fourth over the upper surface of the fuel to insure uniform ignition. The load was monitored by a load cell transducer located below the inner fuel basket and insulated from the heat by baffles that also prevented airflow through the annular space between the center basket and the outer ring of fuel.

RESULTS

Figure 3 is a representative set of fuel load histories for each packing ratio, β. The load-loss rate was obtained simultaneously with the load history by electronically differentiating the signal from the load cell transducer. The differentiated signal was also used to determine the first indication of weight loss for the curves in figure 3 because of its greater sensitivity to changes in the load. Except for $\beta = 0.065$, each curve has an initial negligible load loss.

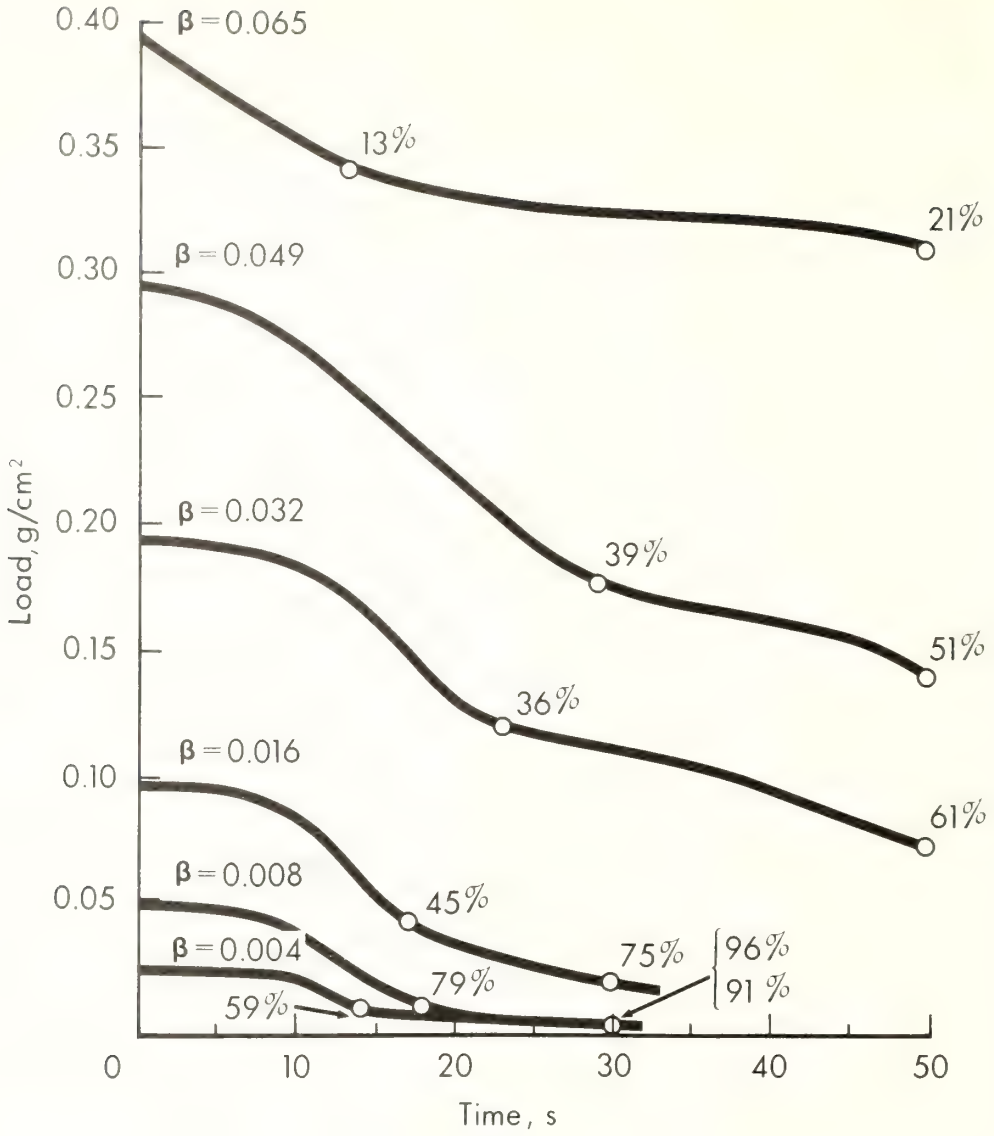

Figure 3.--Typical load histories of burning fuel baskets at six different packing ratios. The percent load loss through combustion is indicated at the end of the first major period of fuel consumption and at 30 seconds for β = 0.004 to β = 0.016 and at 50 seconds for β = 0.032 to β = 0.065.

Five replications of the load history were made at six packing ratios from 0.004 to 0.065. Table 1 is a compilation of the maximum load-loss rate, $\dot{w}$, obtained from the burning basket. Table 2 contains Rothermel's original data for excelsior from horizontal spreading fires. Both sets of data are displayed in figure 4 along with a prediction of $\dot{w}$ according to Rothermel (1972) (appendix B). The prediction differs from the original excelsior data because the results of other fuel sizes were amalgamated by Rothermel to obtain the generalized expression for reaction velocity and thus the maximum load-loss rate.

Table 1.--*Maximum load-loss rate of a burning basket of excelsior at different packing ratios*

Packing ratio	Moisture content fraction of ovendry weight	Maximum load-loss rate
		g/cm^2-s
0.004	0.05	2.82×10^{-3}
		2.82
		2.49
		2.52
		2.60
.008	.05	4.24×10^{-3}
		3.51
		4.02
		4.47
		4.30
.016	.05	4.87×10^{-3}
		6.11
		6.34
		6.57
		5.44
.32	.05	6.48×10^{-3}
		6.42
		6.20
		6.25
		6.82
.64	.05	8.04×10^{-3}
		5.85
		5.16
		5.49
		1.93

Table 2.--*Maximum load-loss rate of a weighed slice of a horizontally spreading fire in excelsior fuel**

Packing ratio	Moisture content fraction of ovendry weight	Maximum load-loss rate
		g/cm^2-s
0.005	0.053	1.84×10^{-3}
	.047	2.34
	.056	2.16
.01	.048	4.24×10^{-3}
	.045	2.91
	.045	2.89
.02	.052	9.08×10^{-3}
	.039	8.40
	.066	4.43
	.050	4.25
	.063	7.64
.03	.054	6.71×10^{-3}
	.053	5.52
	.050	5.85
.04	.059	4.29×10^{-3}
	.062	3.75
	.054	4.57
.05	.056	3.78×10^{-3}
	.056	3.82
	.054	3.56
.06	.058	3.78×10^{-3}
	.054	3.[illegible]
	.057	3.[illegible]

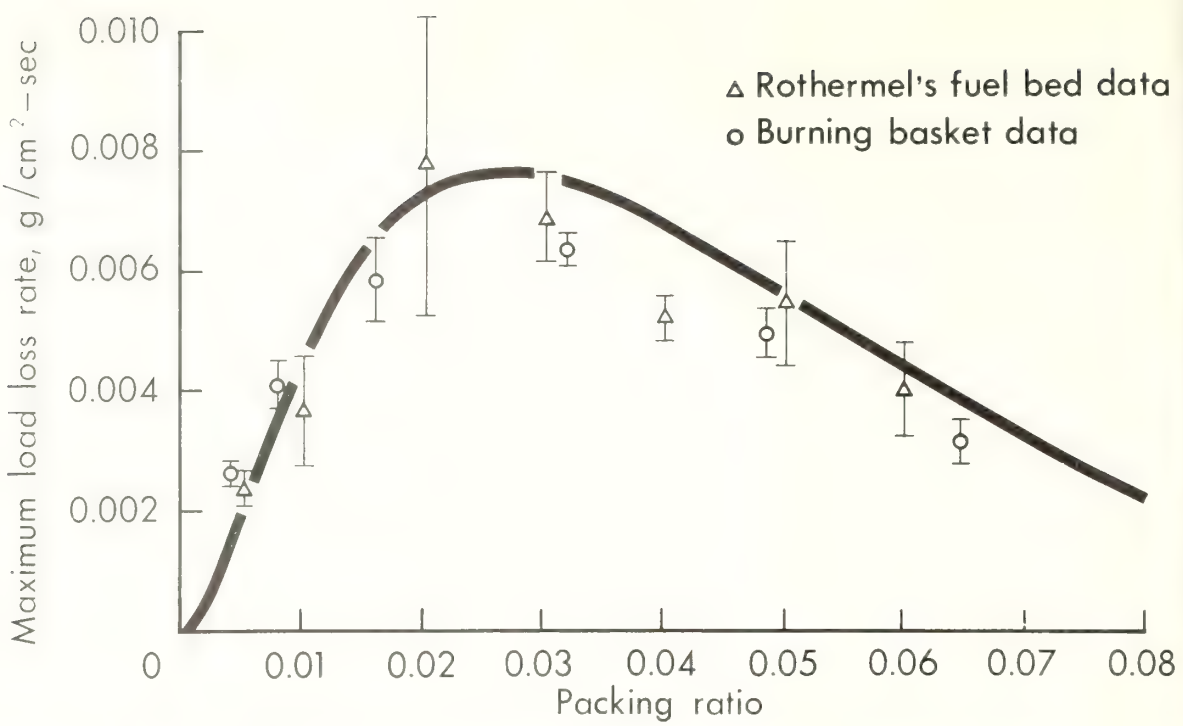

Figure 4.--A plot of the maximum load-loss rate, $\dot{w}$, versus the packing ratio, β, for excelsior burned in a basket and in a fuel bed. The continuous curve was obtained from the expression for $\dot{w}$ in appendix A. The upper and lower extreme are the standard deviation from the mean.

DISCUSSION

The data contained in tables 1 and 2 for the two different methods of obtaining the maximum load-loss rate do not lend themselves to a simple comparison at the same packing ratios. However, assuming that a quadratic model fits these data, we can approximate each data set with a quadratic regression curve, $\dot{w}$ regressed on β, and compare these curves to a quadratic regression of the composite of both data sets. The composite curve expresses fuel loss rate as accurately as the individual data sets if the composite curve has a sum of squared errors (SSE) (squared differences between observed and predicted from quadratic model) not significantly greater than the sum of SSE's from the separate curves. It then follows that the curves are not dissimilar. A statistical test of the data from tables 1 and 2 (appendix C) shows that it is very unlikely that the two data sets are different.

The early load history (fig. 3) of the burning fuel follows a declining sigmoid curve. Shape of the curve varies with packing ratio and is distinguished from other curves through the maximum load-loss rate occurring at the inflection. It is important to determine if the depth was sufficient to achieve the characteristic maximum load-los rate for each packing ratio. Fuel consumption efficiency is a means of examining this

uestion. It is indicated in figure 5 at the end of the [illegible]
ncreasing slope (second knee except at [illegible] following [illegible]
nitial sigmoid curve. For [illegible] 0.03" to [illegible] 0.06", [illegible] the fuel
emains at 50 seconds--well after the initial [illegible]
epth, 15.2 cm, was sufficient for [illegible]
s little as 4 percent of the fuel remain[illegible]
nd shows at least 17 percent more fuel consumed beyond the [illegible]
he initial sigmoid curve was not foreshortened by lack of [illegible]

In the spreading fire, the major rate of fuel consumption is near the front of the ombustion zone--consistent with its early occurrence in the fuel basket--and is of prime importance to the propagation of the fire (Frandsen and Rothermel 1972).

Converting an idealized load history to load-loss history provides with [illegible] reference for comparing the dynamics of burning fuel baskets of constant [illegible] having different depths (initial loads). Because the fuel below the pyrolysis [illegible] has no effect upon the present load-loss history, we can see that the load-loss curve for an extreme depth will have all the characteristics of load-loss curves of [illegible] depth (fig. 5), except that the period of constant load-loss rate becomes longer. The [illegible] of the curves in figure 5 to the right of the second knee is dependent on char buildup. Char formation depends on the mineral content of the fuel and increases with [illegible] depletion that in turn increases with time as the pyrolysis zone travels down into the basket. The char buildup for excelsior is negligible up to and including th[illegible] load-loss rate because the maximum rate occurs early in the load history and the [illegible] content is low (0.03 percent). Whatever the effect, it is the same for both the [illegible] and the basket.

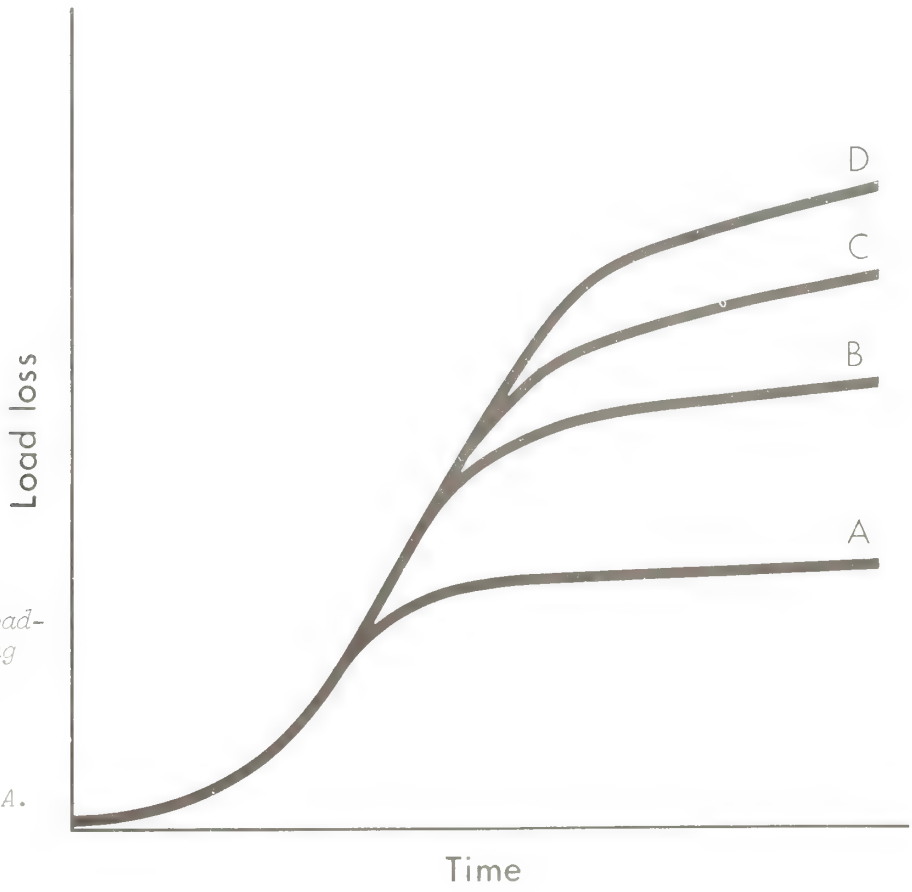

Figure 5.--An idealized load-loss history of a burning fuel basket of extreme depth, curve D, having similar characteristics to a basket of lesser depth, curves C down to A.

The statistical test in appendix C indicates that the alternative method presented here can be used for fuel near the size of excelsior to obtain the reaction velocity used by Rothermel to describe the dynamics of a horizontally spreading fire. Investigations at larger fuel sizes are necessary to extend the range of the usefulness of this method.

This method should be useful in studying fire spread in forest fuels comparable in size to excelsior. Some specific applications that come to mind are; dependence of fire spread on natural variables such as mineral content, moisture content, extractive content, and packing ratio, and also the efficacy of fire-retarding chemicals.

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APPENDIX

Appendix A

Terms

SYMBOL		DEFINITION	UNIT
$\dot{w}$	=	Maximum load-loss rate	g/cm^2-s
w_n	=	Net original ovendry load (less inorganics)	g/cm^2
Γ	=	Reaction velocity	s^{-1}
Γ'	=	Optimum reaction velocity	s^{-1}
Γ'_{max}	=	Maximum optimum reaction velocity	s^{-1}
h	=	Low heat content of fuel	cal/g
I_R	=	Reaction intensity	cal/cm^2-s
δ	=	Fuel depth	cm
σ	=	Surface area-to-volume ratio	cm^{-1}
β	=	Packing ratio, the fraction of bulk volume occupied by fuel	cm^3/cm^3
β_{op}	=	Optimum packing ratio	cm^3/cm^3
ρ_p	=	Ovendry particle density	g/cm^3
η_s	=	Mineral damping coefficient	
η_m	=	Moisture damping coefficient	
S_e	=	Silica free ash content	Fraction of ovendry weight
M_f	=	Fuel moisture content	Fraction of ovendry weight

Appendix B

Derivation of Maximum Load-Loss Rate

Beginning with $\dot{w} = w_n \Gamma$, the net load is expressed as

$$w_n = \rho_p \beta \delta$$

here

ρ_p = ovendry particle density
δ = depth of the fuel basket or fuel slice
β = packing ratio, the fraction of the bulk volume occupied by fuel.

he other term in the expression for $\dot{w}$ is the reaction velocity, Γ. Rothermel (1972 rovides a set of parametric equations for obtaining Γ from initial fuel parameters.

$$\Gamma = \eta_s \eta_m \Gamma'$$

here

η_s = mineral damping coefficient = f (silica free ash content)
η_m = moisture damping coefficient = f (fuel moisture content)
Γ' = optimum reaction velocity

nd

$$\Gamma' = \Gamma'_{max} (\beta/\beta_{op})^A \exp[A(1-\beta/\beta_{op})]$$

$$\Gamma'_{max} = \sigma^{1.5}(495 + 0.0594\ \sigma^{1.5})^{-1}$$

$$\beta_{op} = 3.348\ \sigma^{-0.8189}$$

$$A = 1/(4.774\ \sigma^{-1} - 7.27)$$

σ = particle surface area-to-volume ratio

ubstituting w_n and Γ into $\dot{w}$ gives

$$\dot{w} = \rho_p \beta \Gamma' \eta_s \eta_m$$

rom Rothermel's (1972) original data

ρ_p = 26.12 lbs/ft^2
δ = 0.375 ft
η_m = 0.694 @ M_f = 0.05
η_s = 0.507 @ S_e = 0.0036

ubstituting into $\dot{w}$ we have

$$\dot{w} = 0.0280\ \beta\ \Gamma'$$

ith σ = 1,848 ft^{-1} for excelsior

$$\Gamma' = 15.237\ e^{0.3498}\ [\beta' e^{-\beta'}]^{0.3498}$$

here

$\beta' = \beta/0.00707$

Appendix C

Statistical Test

Statistical test of the similarity between the maximum load-loss rate dependence on packing ratio of the alternative burning basket method and the horizontally spreading fire.

The SSE and degrees of freedom, d.f., are given in the following tabulation. The model assumes a second degree polynomial.

Data set	SSE*	d.f. = n-3
Verticle burn, SSE(V)	9.5600×10^{-6}	27
Horizontal burn, SSE(H)	43.6092×10^{-6}	20
Composite, SSE(C)	58.0511×10^{-6}	50

*Sum of squared errors

Forming F value according to Draper and Smith (1966)

$$F = \frac{(\Delta SSE/\Delta d.f.)}{(SSE(V+H)/d.f.(V+H))}$$

Therefore

$$F = \frac{(4.8819\times10^{-6}/3)}{(53.1692\times10^{-6}/47)} = \frac{(4.8819)(47)}{(53.1692)(3)}$$

$$F = 1.4385$$

Given no difference in the two sets of data the probability of such a value for F, is 0.24. Therefore, we accept the hypothesis that both methods are estimating the same result.

U.S. GOVERNMENT PRINTING OFFICE 1978—777-095 / 23

For. and Range Exp. Stn., Ogden, Utah 84401.

Describes a vertical, cylindrical fuel array that requires less fuel and less time to set up and to measure combustion rates than the flat fuel arrays used previously in laboratory studies of fire. Rates of combustion were comparable in horizontally and vertically (downward) spreading experimental fires.

KEYWORDS: fire spread, excelsior fuel, burning rate, load-loss rate, fire behavior.

Frandsen, William H., and Robert D. Schuette.
1978. Fuel burning rates of downward vs. horizontally spreading fires.
For. and Range Exp. Stn., Ogden, Utah 84401.

Describes a vertical, cylindrical fuel array that requires less fuel and less time to set up and to measure combustion rates than the flat fuel arrays used previously in laboratory studies of fire. Rates of combustion were comparable in horizontally and vertically (downward) spreading experimental fires.

KEYWORDS: fire spread, excelsior fuel, burning rate, load-loss rate, fire behavior.

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RAZING ON NATIONAL FOREST YSTEM LANDS:

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GRAZING ON NATIONAL FOREST SYSTEM LANDS: COSTS OF INCREASING CAPACITY IN THE NORTHERN REGION

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RESEARCH SUMMARY

Sample grazing allotments on Ranger Districts in the Northern Region (USDA Forest Service) were surveyed by questionnaire to determine the feasibility of increasing grazing capacity through additional range improvements. The survey included an inventory of existing grazing capacity and the specific kind and cost of proposed improvements. Costs of improvements were amortized and aggregated for each Forest Service Planning Area. The resulting costs were compared with the increased grazing capacity measured in animal unit months (AUM) to determine the cost per additional unit of capacity.

The results show opportunities to increase grazing capacity by 360,000 AUM over the current capacity of 1,175,000 AUM on National Forests in the Northern Region through investment of $23,300,000. Amortized cost per AUM for improvements ranges from $6 in the eastern part of the Region to $16 in the west, as shown in the following table.

Cost of improvements, additional grazing capacity, and amortized cost per AUM by planning area

Planning area	Current cost of additional grazing capacity	Additional grazing capacity	Amortized cost per additional AUM
	Dollars	AUM	Dollars/AUM
N. Idaho	1,573,600	20,650	15.0
W. Montana	2,312,171	21,473	16.0
Cent. Montana	5,967,161	102,717	8.0
Cent. Rocky Mt.	905,951	11,638	9.6
E. Montana	3,465,628	42,161	8.8
Dakotas	9,101,032	165,936	6.1

CONTENTS

	Page
INTRODUCTION	1
STUDY METHODS AND DATA BASE	3
Representativeness and Expansion of Sampled Allotments	3
Primary Data	4
Secondary Data	5
Calculating Procedures	6
Interpreting the Results	7
PLANNING AREA 1: NORTHERN IDAHO	8
Historical Improvements	8
Replacement Costs and Productivity	9
Past Expenditures	10
Proposed Improvements	11
Productivity of Proposed Improvements	13
PLANNING AREA 2: WESTERN MONTANA	15
Historical Improvements	15
Replacement Costs and Productivity	16
Past Expenditures	16
Proposed Improvements	17
Productivity of Proposed Improvements	17
PLANNING AREA 3: CENTRAL MONTANA	21
Historical Improvements	21
Replacement Costs and Productivity	22
Past Expenditures	23
Proposed Improvements	23
Productivity of Proposed Improvements	25
PLANNING AREA 4: CENTRAL ROCKY MOUNTAINS	27
Historical Improvements	27
Replacement Costs and Productivity	27
Past Expenditures	27
Proposed Improvements	27
Productivity of Proposed Improvements	29
PLANNING AREAS 5A AND 5B: EASTERN MONTANA AND THE DAKOTAS	31
Historical Improvements	33
Replacement Costs and Productivity	33
Past Expenditures	33
Proposed Improvements	34
Productivity of Proposed Improvements	35
SUMMARY FOR NORTHERN REGION	37
Proposed and Historical Improvements	37
Relative Productivity of Improvements	40
An Economic Supply Curve	41
Public Versus Private Funding	43
PUBLICATIONS CITED	44
APPENDIX A - Tables A-1 through A-6	45
APPENDIX B - Definitions	55

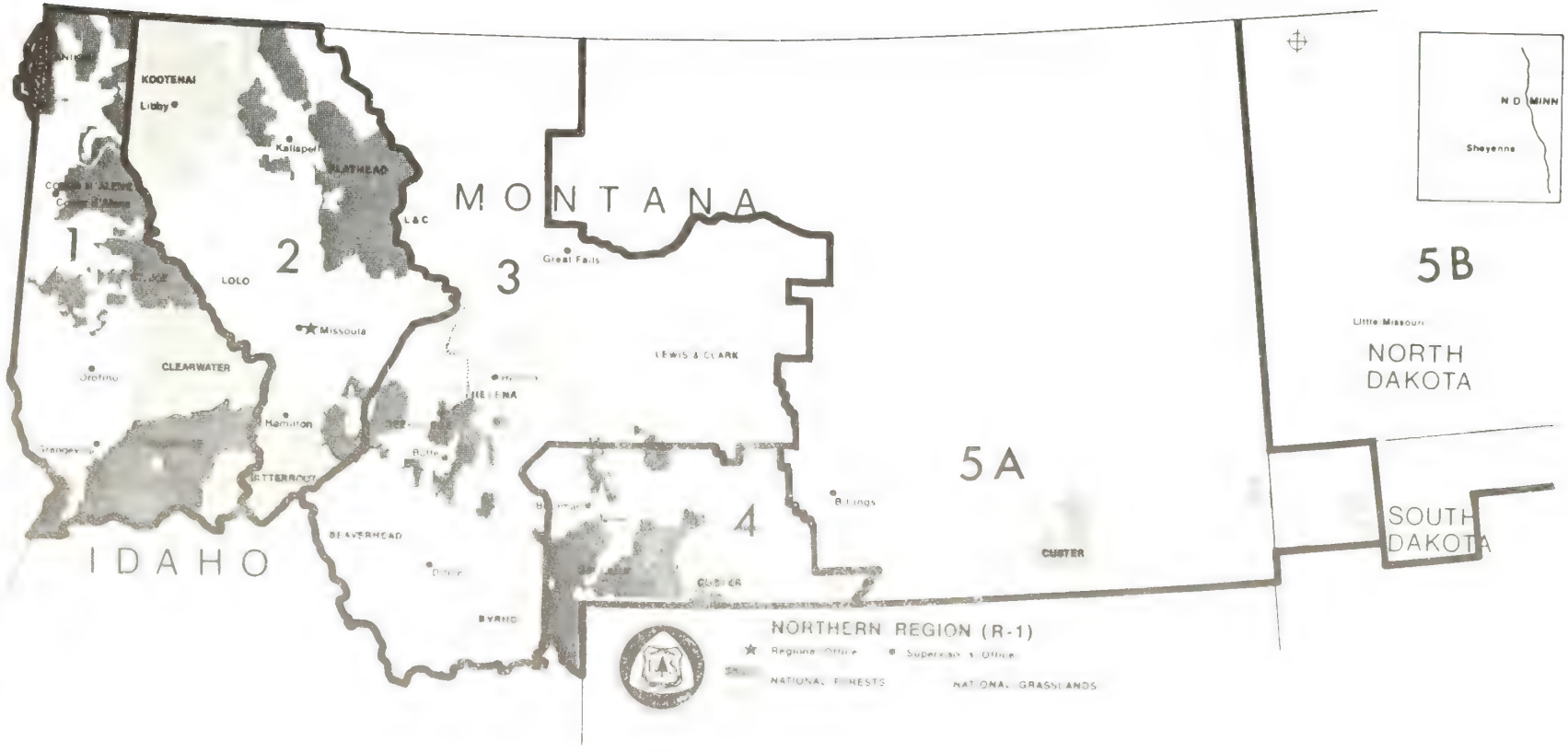

Figure 1.--Location of Northern Region Planning Areas.

INTRODUCTION

In 1974, the Forest and Rangeland Renewable Resources Planning Act was passed by Congress to assure long-range planning of the Nation's renewable resources. One provision of this Act requires:

> An inventory, based on information developed by the Forest Service and other Federal agencies, of present and potential renewable resources, and an evaluation for improving their yield of tangible and intangible goods and services...

In partial response to this provision, this study provides estimates of increased grazing capacity from various range improvement practices in the Northern Region of the Forest Service, U.S. Department of Agriculture. Costs of both the historical and the proposed improvements are also presented.

The Northern Region stretches across rugged northern Idaho, through Montana, and across the Northern Plains of the Dakotas. It extends about 1,000 miles from west to east and, at the extremes, nearly 400 miles from north to south. Because of the variety of conditions in such a large area, findings of this study are presented separately for each of five Planning Areas (fig. 1), defined by common topographic, vegetative, and climatic conditions and having generally comparable range conditions. These areas correspond with those used in the Forest Service planning process and thus facilitate the use of the findings for planning purposes. To the extent possible, findings are also presented for individual National Forests. While the Planning Areas include all lands, regardless of ownership, in the Northern Region, this study is only concerned with National Forest lands. Selected descriptors of the Planning Areas are shown in table 0-1.

Table 0-1.--Sampled and total populations and sample expansion factors

Planning areas	Ranger Districts	Number of allotments: Total	Number of allotments: Percent in sample	Net acreage in grazing: Total	Net acreage in grazing: Percent in sample	Current grazing capacity: Total	Current grazing capacity: Percent in sample	Sample expansion factor 2/
				Acres		AUM		
PLANNING AREA 1								
Clearwater NF	6	59	16.9	128,938	32.4	8,517	31.6	3.16
Panhandle NF	8	59	18.6	119,244	42.5	7,601	36.3	2.76
Nezperce NF	6	56	17.9	629,916	31.5	36,649	25.3	3.95
PLANNING AREA 2								
Bitterroot NF	4	64	12.5	176,449	28.6	11,292	23.1	4.33
Flathead NF	5	27	7.4	89,819	24.2	2,748	34.3	2.91
Kootenai NF	7	53	22.6	107,237	33.7	10,755	28.5	3.51
Lolo NF	6	108	11.1	184,863	45.8	11,775	23.1	4.33
Philipsburg RD 3/	1	28	7.1	74,900	70.0	9,319	13.1	7.63
Lincoln RD 4/	1	16	12.5	24,703	41.3	4,949	7.5	13.31
PLANNING AREA 3								
Beaverhead NF	5	199	15.1	639,110	28.9	174,349	15.5	6.47
Lewis & Clark NF	6	160	7.5	350,228	14.5	51,957	10.2	9.82
Deerlodge NF	3	94	6.4	293,829	36.4	39,119	12.2	8.22
Helena NF	3	78	7.7	210,188	14.1	33,624	10.9	9.18
PLANNING AREA 4								
Gallatin NF	6	170	6.5	297,056	10.1	35,836	10.1	9.94
Beartooth RD 5/	1	28	7.1	45,610	15.4	14,507	14.1	7.07
PLANNING AREA 5A								
Custer, 3 RD's	3	116	15.5	506,736	30.1	164,545	27.2	3.68
PLANNING AREA 5B								
Custer, 4 RD's	4	608	7.2	1,123,338	16.4	557,420	17.1	5.85
REGIONAL TOTALS	75	1,923	1/ 10.3	5,002,164	25.8	1,174,962	18.0	5.55

1/ Because 11 sampled allotments were on transitory ranges, four Ranger Districts had no allotments; they were dropped from the sample. There were, then, data from a total of 198 allotments across the Region.

2/ (Sample expansion factor) = (1.) ÷ (Proportion of total current grazing capacity in sample)

3/ Deerlodge National Forest.

4/ Helena National Forest.

5/ Custer National Forest.

STUDY METHODS AND DATA BASE

Data concerning grazing capacity under current levels of investment, the grazing capacities under an intensive level of investment, and the costs of making these investments were collected from each Ranger District by questionnaire (sample questionnaire available from authors). This information was obtained directly from the individuals with on-the-ground responsibility for grazing management, on the assumption they are most familiar with local conditions and best able to make such estimates.

Respondents were instructed to analyze at least two representative or average grazing allotments in their respective Districts that would draw an average amount of cooperation from permittees in sharing expenses of investments. In addition to providing general descriptive information they estimated the current costs and numbers of units of 38 types of structural and nonstructural improvements needed to fully utilize the grazing capacity of each sampled allotment (see appendix B for investment definitions). In addition, they specified the percentage contribution to the total increase in grazing capacity to be expected from each such improvement and the priority for each improvement.

These sample estimates were then expanded to estimate the proposed improvements, by type of improvement, for each Planning Area. We also developed cost estimates for each additional AUM of capacity by type of improvement. The average investment costs per AUM for the intensive investment program were then compared with the investment costs per AUM of the current grazing capacity. Finally, we summarized this information for the Region as a whole in terms of a supply curve.

Representativeness and Expansion of Sampled Allotments

Because of the variety of physical conditions on individual allotments across the Region and the local importance of grazing on the National Forests, we chose to survey each Ranger District in the Region. While two allotments were surveyed on most Ranger Districts, the Districts on the Beaverhead and Custer National Forests (except the Beartooth) were sampled at a rate of 6 to 18 allotments per Ranger District because of the larger number of allotments there. Furthermore, 11 sampled allotments on the Clearwater, Panhandle, Nezperce, Flathead, Gallatin, and Kootenai National Forests were removed because they were transitory range. Transitory range was dropped from the sample because it has few improvements and no permanent grazing capacity, and is generally not considered for investments. In nine other situations allotments were not sampled because none existed. The final sample used in this study contained data from 198 allotments on 66 of the 75 Ranger Districts in the Region.

As shown in table 0-1, the sample covered more than 1 million of the 5 million acres that are grazed. Sampled allotments included 10 percent of the Region's 1,923 allotments and 18 percent of the total grazing capacity under current levels of investment. Because the percentage of net acreage in grazing represented by the sample (26 percent) is somewhat larger than the percentage of the current grazing capacity represented by the sample (18 percent), the productivity estimates of the investments for range improvements in the Region may be somewhat conservative.

We based expansion of our sample on current grazing capacity. Grazing capacity is an estimate of the maximum average number of AUM that can be supported without damaging the range resource and, for each allotment, is a constant for a given management system and set of improvements. In contrast, actual use fluctuates from year to year in response to weather conditions and, perhaps, in response to the market demand for livestock.

It would have been more desirable to weight our sample data concerning improvements necessary to move from the current to a higher capacity by the differences between those capacities. Unfortunately, the higher capacities were not known in advance of this study; indeed, estimates of the higher capacities are one result of this study.

For any grouping of similar Ranger Districts, we expanded our sample in the following manner:

$$\left[\begin{array}{c}\text{Sample}\\ \text{expansion}\\ \text{factor}\end{array}\right] = \left[\frac{1.0}{(\text{Proportion of current grazing capacity in sample})}\right]$$

For the Bitterroot National Forest in Planning Area 2, then

$$\left[\begin{array}{c}\text{Sample}\\ \text{expansion}\\ \text{factor}\end{array}\right] = \left[\frac{1.0}{0.231}\right] = [4.33]$$

If three cattleguards were proposed for the allotments sampled on the Bitterroot, for example, we calculated

$$\left[\begin{array}{c}\text{Total number}\\ \text{cattleguards}\\ \text{proposed for Bitterroot}\end{array}\right] = \left[\begin{array}{c}\text{Number proposed}\\ \text{for sample}\\ \text{allotments}\end{array}\right] \times \left[\begin{array}{c}\text{Sample}\\ \text{expansion}\\ \text{factor}\end{array}\right]$$

$$= [3] \times [4.33]$$

$$= 12.99 \text{ or } 13$$

To the extent possible, sample expansion factors were calculated for individual National Forests. Where National Forests were split between Planning Areas, sample expansion factors were calculated for Ranger Districts.

Primary Data

By questionnaire we developed the following principal types of primary data for each sampled allotment:

Type of information	*Comment*
Proposed range improvements	The questionnaires reported the specific kinds of improvements necessary to increase grazing capacity; because the sizes and materials necessary for structural improvements varied a good bit by allotment, we categorized the improvements by their functions for use in cost comparisons between Planning Areas (e.g., cattleguards, stock trails, and stock bridges were categorized as "Access" improvements).

pe of information	*Manner*
cal costs prevailing in early 1976 to nstruct or implement one unit of each nd of improvement.	For examining proposed improvements for a given National Forest, we used the average cost of the sampled allotments on that Forest. Because current costs are not available for certain improvements on particular Forests, we used the average costs from all allotments within a Planning Area to calculate the replacement costs of historical improvements. Where current costs were not available for a Planning Unit, we used average costs in the Region.
crease in grazing capacity for entire lotment given entire package of pro-sed improvements; percentage of increase e to each category of improvement.	Improvements were considered as "packages" of investments and do not, on particular allotments, permit an increase in grazing capacity by themselves; however, at the Planning Area level we have aggregated the information to provide rough measures of expected productivity of each category of investment.

Secondary Data

To supplement the primary survey data gathered for this study, we assembled certain ckground information. The principal types of information, their sources, and the nner in which they are used in this report are:

pe of Information	*Source*	*Manner of use*
storical expenditures r range improvements.	Regional Office[1]	Determine proportions contributed by permittees, Forest Service, and other Government sources.
75 inventory of his-rical range improvements.	Regional Office[1]	Determine replacement costs of improvements supporting present grazing; contrast with costs of proposed improvements.
ortization schedules for nge improvements.	FRES study and interest tables[2]	Determine average annual cost of improvements using an interest rate of 10 percent.

[1]USDA Forest Service. 1975. Statistical summation of range improvements. Computer intout of range inventory of existing improvements and accounts of cumulative invest-nts by Ranger District and National Forest, March 24, 1975, USDA-FS, R-1, Missoula, ontana. (Unpublished computer printout).

[2]See Duran and Kaiser (1972) regarding FRES, and Lundgren (1971, p. 115) for interest rmula and tables.

Type of information	*Source*	*Manner of use*
Current grazing capacity, 1975 actual grazing, physical descriptors.	Sampled allotments and individual National Forests	Determine current average costs per AUM and general descriptions.
Data on ranch sizes and Planning Area populations.	Census[3]	General descriptions.

Calculating Procedures

This study considers a large number of improvements over many administrative uni in the Northern Region. In each of the sections of this report that are devoted to a single Planning Area, the calculations shown in Table 0-2 were used to evaluate the productivity of historical and proposed range improvements. The detail available for the sampled allotments was foregone to derive averages at the Planning Area level. Because basic information is lacking, it is not possible to estimate the productivity of individual categories of historical improvements. Throughout this study, replacement and current costs are expressed in terms of 1976 dollars.

Each of the following sections contains a similar set of tables. To thoroughly understand the way in which the table entries were derived, we urge the reader to carefully read the section covering Planning Area 1, for the methodology is presented in more detail there than in the other sections. The Regional summary simply abstrac data from the other sections.

Table 0-2.--Calculations to evaluate historical and proposed improvements

Level of information	Historical improvements	Proposed improvements
1. Kind of improvement	[Replacement cost of improvements] = [1975 R.O. inventory] X [Current Planning Area average cost]	[Cost of improvements] = [Expansions of proposed improvements from questionnaires] X [Current National Forest average cost]
2. Category of improvement	Sum replacement costs to get replacement cost of category of improvements.	Sum costs to get cost of category of improvements
3. Category of improvement	[Amortized replacement cost of category] = [Replacement cost of category] X [Ten percent Interest-payment factor 1/]	[Amortized cost of category] = [Cost of category] X [Ten percent Interest-payment factor 1/]
4. Category of improvement	-- -- -- -- -- -- -- -- -- -- --	Amortized cost of category per additional AUM = Amortized cost of category / Additional grazing capacity due to category
5. All improvements	Sum to get amortized replacement cost of all improvements.	Sum to get total amortized cost per added AUM.
6. All improvements	[Total amortized replacement costs per current AUM] = [Total amortized replacement costs] / [Total current grazing capacity]	-- -- -- -- -- -- -- -- -- -- -- -- --

1/ See Appendix D.

[3]Population from U.S. Bureau of the Census (1973, p. 28-31) and farm data from U. Bureau of the Census (1972, p. 253).

Interpreting the Results

Care must be taken in interpreting the results presented in the following chapters. irst, most of the data were obtained as subjective estimates, albeit by professionals, nd therefore may not be as consistent or precise as desired. Nevertheless, these are he best data available Regionwide.

Second, not all opportunities for range improvements may be represented. Because he sample is biased toward the poorer quality range, the data may show fewer, less roductive improvements than is actually the case. Furthermore, some of the inter- iewers appeared to be more imaginative in perceiving new opportunities than others. hus, the opportunities addressed in this study probably do not include all that ctually exist.

Third, for the improvement opportunities that were considered, not all the associ- ted costs were recorded. Those concerned with administration and maintenance for the llotments were omitted. To the extent that these costs increase with increasing ntensity of management, the cost estimates presented in this study are low. Another ost problem involves differences in cost among Forests and Planning Areas for the same mprovement. For example, on the Deerlodge National Forest one type of fence costs 4,000 per mile while a similar fence costs less than $2,000 per mile on the Beaverhead. imilar costs variations can be found in most of the other improvement categories. hile a small amount of this variation may be attributed to error in estimation, we elieve most of the variation reflects differences in materials, terrain, design, and ther related factors.

A fourth consideration in interpreting the results deals with projections of AUM ssociated with improvement opportunities. Not all of the increases in production will e available to cattle, because some forage for wildlife is also a Forest Service bjective. Furthermore, in some cases the improvements are necessary just to maintain n allotment's present grazing capacity and no increase in yields will result.

Fifth, because of the joint nature of some proposed improvements, comparing data or individual improvement categories is rather risky, especially at the Forest level. or instance, fencing on a particular National Forest might be attractively efficient ompared to water development. However, fencing without water development might be seless. Because of this problem, the summary chapter does not attempt to judge the fficiency of individual improvement opportunities.

A final consideration involves the problems of interpreting the historical cost ata which are presented in terms of 1976 dollars. Age of the improvements was not vailable nor was the expected length of use. Thus, the replacement cost was calculated ssuming all past improvements would be redone and would last as long as the proposed mprovements. This procedure may lead to double counting where past improvements eplaced previous improvements. Offsetting this effect is the fact that some range mprovements have probably not been recorded and thus not counted in this study. In he case of the National Grasslands, some costs may be omitted, because records were vailable only since the Forest Service assumed administration.

In spite of these limitations, we feel the results in the following sections epresent the best data available at this time for the Northern Region. They can serve s useful indicators of relative opportunities, their costs, and their productivity for lanning purposes.

PLANNING AREA 1: NORTHERN IDAHO

Planning Area 1 covers northern Idaho and includes the Idaho Panhandle, the Clearwater, and the Nezperce National Forests. Grazing is limited to 878,000 acres (14 percent) of the total 6.2 million acres. In 1975, 174 allotments were grazed by 226 permittees, representing 5.5 percent of the 4,095 farms and ranches in the area. Livestock grazing was concentrated on the Nezperce, the southernmost forest, with 32,000 AUM. There were about 8,400 AUM on the Clearwater and 5,400 AUM on the Panhand Total actual grazing in this area accounted for slightly more than 4 percent of the Region's total in 1975, and the grazing capacity accounted for about 4.5 percent of th Region's total. Selected descriptors of the area are presented in table 1-1.

Historical Improvements

Past investments have been made in a variety of improvements to permit utilizatio of the range resources in the Planning Area. The range improvements in Planning Area are summarized in table 1-2. Generally, investments have been made primarily in cattleguards, water, fences, and cabins. Few investments in range improvement practice have been made.

Table 1-1.--Selected descriptors of Planning Area 1, 1975

National Forest	Number of allotments	Number of Permittees	Total net acreage	Net grazing acreage: Total	Net grazing acreage: Percent under timber canopy	Current grazing capacity
						AUM
Clearwater	59	77	1,825,690	128,938	60	8,517
Panhandle	59	76	2,208,784	119,244	74	7,601
Nezperce	56	73	2,150,498	629,916	88	36,649
Planning Area Total	174	226	6,184,972	878,098	82	52,767
Planning Area as percent of Northern Region	9	10	26	18	--	4

Table 1-2.--Number of historical improvements in Planning Area 1 by National Forests

Kind of Improvement	Clearwater N.F.	Panhandle N.F.	Nezperce N.F.	Planning Area 1 Total
STRUCTURAL				
A 1. Cattleguard	19	18	26	63
2. Stock trail(miles)	12.8	4.8	62.8	80.4
3. Stock bridge			8	8
B 4-5. Rain tanks			6	6
C 6-8. Spring tanks	1		214	216
E 13-14 Water trans'm (miles)		3.1		3.1
F 15. Dam & reservoir	17		11	28
G 16. Other water dev.		1		2
H 17-21. Fence (miles)	26.3	16.4	139.5	182.3
I 22. Cabin	4	1	23	28
Barn	2			4
Corral	8	1	27	37
Loading chute	5		1	6
Dipping vat		1		1
NONSTRUCTURAL				
J 1-2. Ground prep(ac)		25		25
K 3-6. Seeding(ac)	12	18	230	260
L 7-8. Fertilizer(ac)	3	20		23
N 11-14. Plant Control(ac)	312	95		407

Replacement Costs and Productivity

The present grazing capacity is, in part, dependent upon the investments already on the ground. The inventory of present improvements and the costs required to replace them, based on the current prices found in this study, are itemized in table 1-3. The total replacement cost would be about three-quarters of a million dollars.

The last column in table 1-3 lists the equivalent annual investments that would be required to replace the historical level of improvements. In total this is approximately $90,000 per year. A rough index of the productivity of these improvements can be obtained by dividing the amortized value by the grazing capacity.

Grazing capacity	52,767 AUM
Total amortized cost of improvements	$90,391
Cost per AUM	$1.71

Table 1-3.--Calculation of total and amortized replacement costs of historical improvements in Planning Area 1

Type of improvement	Existing number	Replacement cost Per Unit	Replacement cost Total	Category replacement cost	Useful life	Amortized replacement cost
		Dollars	Dollars	Dollars	(Years)	Dollars
A 1 Cattleguard	63	1352	85,176			
2 Stock trail (mi)	80.4	518	41,647	168,823	40	17,264
3 Stock bridge	8	5250	42,000			
B Tanks	6	1300	7,800	7,800	30	827
C Spring, tanks	216	486	104,976	104,976	30	11,136
E Water transmission (mi)	3.1	1152	3,571	3,571	30	379
F Dam & reservoir	28	965	27,020	27,020	30	2,866
G Other water develop.	2	157	314	314	30	33
H Fence (mi)	182.3	1119	203,994	203,994	25	22,474
I Cabin	28	5000	140,000			
Barn	4	5000	20,000			
Corral	37	1000	37,000	200,500	10	32,630
Loading chute	6	500	3,000			
Dipping vat	1	500	500			
Structural Subtotal			716,998			87,609
J Ground preparation (ac)	25	100	2,500	2,500	5	659
K Seeding (ac)	260	12	3,120	3,120	30	331
L Fertilizer (ac)	23	23	529	529	3	213
N Plant control (ac)	407	30	12,011	12,011	15	1,579
Nonstructural Subtotal			18,160			2,782
GRAND TOTAL			735,158			90,391

In the past, a very simple, extensive range management has been practiced. Essentially, fences bounded the allotments and the cattle ate whatever forage occurred naturally. To add more cattle in any area requires investing in relatively expensive improvements such as fertilization, shrub control, and water developments. Most of the rest of this chapter discusses estimates of expected costs and results of increasing grazing capacity beyond present levels.

Past Expenditures

Past expenditures in Planning Area 1 amounted to only 9 percent of the Region's range management expenditures (table 1-4). However, since the Area supports only 4 percent of the grazing capacity, this is not surprising. Most of the funds have come from sources other than the range improvement accounts such as Job Corps, fire crews, and particularly range administration. About one-fifth has come from the Forest Service range improvement accounts and the permittees in roughly equal amounts.

Table 1-4.--Historical expenditures for improvements in Planning Area 1 in total and as a percentage of total expenditures in the Northern Region by sources of funds

Sources of funds	Expenditures	
	Dollars	As percentage of expenditures in Region
Forest Service range improvements	153,900	4
Other Forest Service[1/]	620,200	25
Permittees	151,400	5
ALL	925,500	9

1/ Includes all Federal Government expenditures not included in Forest Service range accounts 052 and 053 including range administration and planning, Job Corps, fire crew, etc.

Proposed Improvements

The sampling methodology used in this study was discussed earlier. Between 25 and 0 percent of actual grazing use and current carrying capacities were sampled on the hree forests making up this Planning Area. The 33 sampled allotments indicate there s the potential to increase the Area's carrying capacity by more than a third.

Estimates of the specific kinds of proposed investments and their costs are detailed, by National Forests, in table 1-5. The projected Planning Area total cost for structural mprovements is $712,000 with the Nezperce comprising about half the total. Emphasis is centered on fencing and improvements to facilitate access. Nonstructural improvements would cost about $860,000, with the Nezperce again comprising over half. Seeding, fertilization, and plant control are the major items.

The particular kinds of improvements requested for each sample allotment are a function of already existing improvements; local physical and climatic conditions; and, to some extent, the inclinations of the permittees to share in costs. Even within many of the categories listed in table 1-5, there is substantial variation. For example, cattleguards can be made of railroad rails or 2- by 8-inch planks and can vary from 9 to 24 feet in length. As a consequence, the cost for cattleguards varies substantially. On the Clearwater National Forest (which includes two sample allotments), the cost per cattleguard averaged about $2,556 ($23,000 : 9), on the Panhandle about $2,250, and on the Nezperce about $995.

A comparison of the replacement costs of historical improvements to the cost of proposed improvements suggest a change in emphasis:

	Replacement cost of existing improvements	*Cost of proposed improvements*
Structural	98	45
Nonstructural	2	55

[illegible] and their costs on sampled allotments and estimates for Planning Area 1

Type of improvement	Unit	Sampled allotments: Clearwater N.F. Units	Clearwater N.F. Cost	Panhandle N.F. Units	Panhandle N.F. Cost	Nezperce N.F. Units	Nezperce N.F. Cost	Expansion to N.F.s 1/: Clearwater N.F. Units	Clearwater N.F. Cost	Panhandle N.F. Units	Panhandle N.F. Cost	Nezperce N.F. Units	Nezperce N.F. Cost	Planning Area Total cost
			Dollars		Dollars		Dollars		Dollars		Dollars		Dollars	Dollars
STRUCTURAL IMPROVEMENTS														
ACCESS														
A 1 Cattleguard	each	[illegible]	23,000	4	9,000	31	30,850	28	71,568	11	24,750	122	121,390	217,708
Stock trail	mile	6.0	,500			1.0	1,000	19.0	7,923			4.0	4,000	11,923
Stock bridge	each					2	10,500					8	42,000	42,000
WATER DEVELOPMENTS														
C 7 Spring, metal tank	each	7	3,500			9	4,300	22	11,000			36	17,208	28,208
F 15 [illegible]	each	4	4,800			1	200	13	15,600			4	800	16,400
G 16 Other water development	each	7	1,100					22	3,454					3,454
FENCE														
H 17 Boundary, N.F.	mile	.7	6,200	2.0	3,000	10.1	10,000	8.5	19,516	5.5	8,250	39.5	39,500	67,266
18 Boundary, allotment	mile	7.	10,800	3.0	5,000	5.5	6,500	22.2	34,255	8.3	13,836	21.7	25,649	73,740
19 Interior, allotment	mile	15.0	12,400	4.7	7,400	35.5	32,850	47.5	38,282	13.0	20,462	140.3	129,778	189,522
20 Water source	mile	1.0	,000					3.2	16,000					16,000
21 Right-of-way	mile													
I 22 Miscellaneous structural			5,000		11,4[illegible]				15,822		30,[illegible]03			46,125
Structural subtotal			74,[illegible]		35,400		96,200		234,420		97,601		380,325	712,346
NONSTRUCTURAL IMPROVEMENTS														
GROUND PREPARATION														
J 1 [illegible]	acres	[illegible]	500					16	1,600					1,600
SEEDING														
K 3 Broadcast, ground	acres	[illegible]	200			[illegible]	300	16	640			79	1,185	1,825
4 Broadcast, air	acres	2,000	10,000			1,400	27,500	6,329	31,645			5,534	110,680	142,325
6 Interseed	acres					200	2,000					791	7,910	7,910
FERTILIZATION														
[illegible] Plant establishment	acres	5	50					16	160					160
6 Increase production	acres	[illegible]	47,500			500	26,000	8,861	150,637			1,976	101,752	253,389
PLANT CONTROL														
[illegible] 11 Burning	[illegible]	1[illegible]	3,000					43	9,600					9,600
12 [illegible]	acres					200	10,000					791	39,550	39,550
13 Chemical	acres	1,305	,300	[illegible]	22,995	1,420	42,700	4,130	66,080	1,810	63,350	5,631	168,930	298,360
14 Hand	acres	300	15,[illegible]					949	47,450					47,450
O 15 Rodent control	acres	100	1,000			[illegible]	[illegible]	1[illegible]	3,160			99	1,980	5,140
[illegible] nonstructural			14,000		,[illegible]				44,303		9,642			53,945
Nonstructural subtotal			[illegible]		[illegible]		109,000		355,275		72,992		432,987	861,254
GRAND TOTAL			186,850		61,895		205,200		589,695		170,593		813,312	1,573,600

1/ Calculated by multiplying sample data on physical improvements for each National Forest by sample expansion factors in Table 1. This product was rounded off and then multiplied by the average unit price for each National Forest.

Apparently a substantial increase in nonstructural improvements is called for. owever, some of this difference is probably due to the fact that nonstructural treat- nts were more likely to be overlooked in the survey of historical improvements than adily identifiable structural features. This situation also applies to similar nterpretations in later chapters. Still some shift in emphasis is apparent.

Productivity of Proposed Improvements

The range specialists also indicated the proportion of each allotment's total ncrease in grazing capacity, given requested improvements, that would be due to each ategory of improvements. As illustrated in table 1-6, this information permitted an pproximation of the importance of each category. We say "approximation" because here, nd throughout the study, we recognized that improvements frequently come in packages hat are difficult to subdivide for analysis. For example, plant control and seeding ight be useless if no water is available. For this reason we urge caution in interpret- ng the results too closely. Rather, our analysis indicates potential for further tudy if specific areas or improvements are involved. In some cases no additional AUM re produced by additional investments because these investments are needed to maintain resent levels of capacity. The "miscellaneous structural" category for the Panhandle ational Forest is an example of this situation.

At this point, we have developed the following information by National Forest by ategory of improvement:

--the current total cost of proposed improvements
--the total increase in grazing capacity.

fter one more calculation, we can estimate the cost of increasing grazing capacity per UM.

All of our grazing capacity information is on an annual basis, but our cost nformation is in terms of total cost per unit of improvement. Most improvements have useful life span of a number of years. To put cost information on an annual basis, hen, we must amortize costs over the estimates of useful life found in appendix A. The esults of these calculations, and estimates of the cost per added AUM of proposed mprovements are presented in table 1-6.

If all the requested investments were made on the Planning Area, the grazing apacity on the National Forests could be increased annually by more than 20,000 AUM. he amortized annual cost would be about $15.00 with the most heavily used Nezperce aving the lowest costs by far. Structural improvements promise much lower costs per nit output. For the Planning Area, over 60 percent of the increase in grazing capacity s promised by about 10 percent of the total projected expenditures. But it should be ecognized that some of those investments require nonstructural investments, particularly ertilization and plant control, in order to be effective.

Table 1-6.--Calculation of amortized costs of additional AUM by type of improvement in Planning Area 1

Type of improvement	Life-span	Clearwater National Forest				Panhandle National Forest			
		(2) Total projected costs	(3) Annual amortized costs 1/	(4) Additional AUM 2/	Annual amortized cost per additional AUM 3/	Total projected costs	Annual amortized costs	Additional AUM	Annual amortized cost per additional AUM
	Years	Dollars		AUM		Dollars		AUM	Dollars
A Access	40	79,491	8,129	259	31.4	24,750	2531	55	46.0
B Rain tanks	[illegible]								
C Spring tanks	30	11,000	1,167	184	6.3				
F Dam & reservoir	[illegible]	15,600	1,655	184	9.0				
G Other water develop.	30	3,454	366	117	3.1				
H Fences	25	109,053	12,014	633	19.0	42,548	4,687	[illegible]	13.4
I Miscellaneous	10	15,822	2,575	19	135.5	30,303	4,932	0	6/
STRUCTURAL Subtotal	--	[illegible]4,420	25,906	1,396	18.6	97,601	12,150	405	30.0
J Ground preparation	[illegible]	1,600	422	22	19.2				
K Seeding	30	32,285	3,425	370	9.3				
L Fertilization	3	150,797	60,636	807	75.1				
N Plant control	15	123,130	16,188	266	60.9	63,350	8,329	444	18.8
O Rodent control	5	3,160	834	6	138.9				
P Miscellaneous	1	44,303	48,733	196	248.6	9,642	10,606	63	168.4
NONSTRUCTURAL Subtotal	--	355,275	130,238	1,667	78.1	72,992	18,935	507	37.4
GRAND TOTAL	--	589,695	156,144	3,063	51.0	170,593	31,085	912	34.1

1/ Appendix Table A-6.
2/ Table 1-5.
3/ Column 2 multiplied by 10% interest factor from Appendix Table A-6.
4/ Expanded sample data from Appendix A-1.
5/ Column 3 divided by Column 4.
6/ Infinite

Table 1-6.--Continued

Type of investment	Life-span	Nezperce National Forest				Planning Area 1			
		Total projected costs	Annual amortized costs	Additional AUM	Annual amortized cost per additional AUM	Total projected costs	Annual amortized costs	Additional AUM	Annual amortized cost per additional AUM
	Years	Dollars		AUM		Dollars		AUM	Dollars
A Access	40	167,390	17,117	1,660	10.3	271,631	27,777	1,974	14.1
B Rain tanks	30								
C Spring tanks	30	17,208	1,825	4,099	0.4	28,208	2,992	4,283	0.7
F Dam & reservoir	30	800	85	379	0.2	16,400	1,740	563	3.1
G Other water develop.	30					3,454	366	117	3.1
H Fences	25	[illegible]	21,475	3,122	6.9	346,528	38,176	4,105	9.3
I Miscellaneous	10					46,125	7,507	19	395.1
STRUCTURAL Subtotal		380,325	40,502	9,260	4.4	712,346	78,558	11,061	7.1
J Ground preparation	5					1,600	422	22	19.2
K Seeding	30	119,775	12,706	3,818	3.3	152,060	16,131	4,186	3.8
L Fertilization	[illegible]	102,752	41,317	1,024	40.4	253,549	101,953	1,831	55.7
N Plant control	15	208,480	27,410	2,557	10.7	394,960	51,927	3,267	15.9
O Rodent control	[illegible]	1,980	522	16	32.6	5,140	1,356	22	61.6
P Miscellaneous	1					53,945	59,339	259	229.1
NONSTRUCTURAL Subtotal		432,987	81,955	7,414	11.0	861,254	231,128	9,589	24.1
GRAND TOTAL		810,909	122,457	16,675	7.3	1,573,600	309,686	20,650	15.0

PLANNING AREA 2: WESTERN MONTANA

Planning Area 2 is characterized by rugged mountain peaks and a few broad valleys. : includes four entire National Forests and single Ranger Districts from two others. h 1970, there were 157,000 people and 3,800 ranches and farms, including 268 permit- ees, in this Indiana-size Area.

While the acreage of this area is about one-third of the total acreage of the egion, grazing is severely limited. The Area has only 13 percent of the Region's razing acreage and 4 percent of the grazing capacity (table 2-1).

Historical Improvements

Existing range improvements in this Area are summarized in table 2-2. The improve- ents are mainly for controlling livestock: cattleguards, corrals, and loading chutes. ater is relatively abundant and little investment has been aimed at improving forage roductivity.

Table 2-1.--Selected descriptors of Planning Area 2, 1975

Administrative unit	Number of allotments	Number of permittees	Total net acreage	Net grazing acreage: Total	Net grazing acreage: Percent under timber canopy	Current grazing capacity
						AUM
Bitterroot N.F.	64	56	1,579,561	176,449	67	11,292
Flathead N.F.	27	27	2,349,876	89,819	75	2,748
Lolo N.F.	108	77	2,737,901	184,863	86	11,775
Kootenai N.F.	53	62	1,870,475	107,237	84	10,755
Philipsburg R.D.	28	33	398,268	74,900	83	9,319
Lincoln R.D.	16	13	327,000	24,703	41	4,949
Planning Area Total	296	268	8,763,081	657,971	77	50,838
Planning Area as percent of Northern Region	15	12	36	13		4

Table 2-2.--Calculation of total and amortized replacement costs of historical improvements in Planning Area 2

Type of improvement	Existing number	Replacement cost: Per unit	Replacement cost: Total	Category replacement cost	Useful life	Amortized replacement cost
		Dollars	Dollars	Dollars	Years	Dollars
A 1 Cattleguard	198	1,297	256,806	291,704	40	29,829
2 Stock trail (mi)	27.5	1,269	34,898			
B Tanks	1	1,300	1,300	1,300	30	138
C Spring, tanks	198	497	98,406	98,406	30	10,439
D Wells	1	1,167	1,167	1,167	30	124
E Water transmission (mi)	1.4	4,866	6,812	6,812	30	723
F Dam & Reservoir	11	333	3,663	3,663	30	388
G Other water development	8	10	80	80	30	8
H Fence (mi)	471.0	2,335	1,099,785	1,099,785	25	121,162
I Cabin	1	5,000	5,000			
Corral	21	1,000	21,000	27,500	10	4,475
Loading chute	3	500	1,500			
Structural Subtotal			1,530,417			167,286
K Seeding (ac)	4,694	12	56,328	56,328	30	5,975
L Fertilizer (ac)	7	4	28	28	3	11
M Water retention (ac)	104	10	1,040	1,040	30	110
N Plant control (ac)	670	7	4,690	4,690	15	617
O Rodent control (ac)	120	1	120	120	5	32
Nonstructural Subtotal			62,206			6,745
GRAND TOTAL			1,592,623			174,031

Replacement Costs and Productivity

The replacement costs of the historical improvements are presented in table 2-2. At today's costs, they represent an investment of $1,590,000. This is nearly 7 percen of the replacement costs of all improvements in the Region.

The last column in the table lists the equivalent annual investments that would b required to maintain the historical level of improvements. In total this would amount to about $174,000 per year. We can now calculate a rough index of the productivity of these improvements:

Grazing capacity	50,838 AUM
Total amortized cost of improvements	$174,031.00
Cost per AUM	$ 3.42

Past Expenditures

Past expenditures in the Planning Area were estimated to be 7 percent of the Region's total investment program for developing grazing resources on National Forests (table 2-3). This $700,000 cumulative investment supports 4 percent of the Region's total grazing capacity. About one-third of the funds came from Forest Service range improvement, other Forest Service, and permittee accounts respectively.

Table 2-3.--Historical expenditures for [illegible] Area 2 in total and percent [illegible] in the Northern Region by sources of funds

Source of funds	Dollars	As percent of expenditures in Region
Forest Service range improvements	[illegible],400	
Other Forest Service	224,300	
Permittees	229,600	
ALL	702,300	

Proposed Improvements

The 24 Ranger Districts in Planning Area 2 provided sample data for 38 allotments. The proposed improvements are presented by administrative unit for the sampled allotments in appendix table A-2; projections to total estimates for those units are given in table 2-4.

In total, the estimated improvements would cost $2.3 million. The most critical improvements would be in fencing of all types; access structures are the other main item. Investments for water developments would continue to be relatively modest. The control of unwanted vegetation is the most important kind of ground treatment that is proposed.

As was found for every Planning Area, the proposed improvements, while still heavily weighted towards structures, reflect an increased concern for direct ground treatments:

	Replacement costs of existing improvements (percent)	*Costs of proposed improvements (percent)*
Structural	96	79
Nonstructural	4	21

Productivity of Proposed Improvements

Given the total investment costs of the proposed improvements, we can calculate the annual-equivalent or amortized cost of these improvements (table 2-5). From our sample data, we are able to approximate the added capacity that would result to each category of improvement and, finally, to approximate the cost per additional AUM of capacity (table 2-6).

The Bitterroot National Forest--which had the largest investments--also had the highest average cost for increasing capacity; the Philipsburg Ranger District had the lowest cost. Overall, it would cost $16 on the average to increase capacity by one AUM in this Planning Area.

Table 2-4.--Total proposed improvements and their costs for Planning Area 2

	Type of improvement	Bitterroot N. F.		Flathead N.F.		Kootenai N. F.		Lolo N. F.		Philipsburg R. D.		Lincoln R. D.		Planning Area
		Units	Cost	Units	Cost	Units	Cost	Unit	Cost	Units	Cost	Units	Cost	Total costs
			Dollars		Dollars		Dollars		Dollars		Dollars		Dollars	Dollars
A	1 Cattleguard	35	61,688	23	39,100	49	42,962	48	57,853	15	16,200	13	19,500	237,303
	2 Stock trail (mi)	17	17,000			4	160					13	26,000	43,160
	3 Stock bridge					4	60,000							60,000
C	6 Spring, wood tank					4	1,200					40	33,333	34,533
	7 Spring, metal tank	80	21,333			25	11,714	56	22,831	15	12,000	27	20,250	88,128
E	13 Water pipe (mi)	9	11,250					13	4,333			8	39,333	54,916
	14 Water ditch (mi)	4	10,000			4	120,000							130,000
F	15 Dam & reservoir					11	3,667							3,667
G	16 Other water develop							1,299	12,990					12,990
H	17 Fence, boundary (mi)	21.6	43,200					17.3	29,843					73,043
	18 Fence, allot. boundary (mi)	62.8	200,094	14.6	27,594	56.1	118,862	17.3	21,193	7.6	22,800	26.7	66,750	457,293
	19 Fence, interior (mi)	106.1	266,766	20.4	38,556	21.4	46,049	36.8	52,819	30.5	99,125	53.3	119,925	623.240
	20 Fence, water source (mi)	3.2	6,400			0.4	120	1.3	1,300					7,820
	STRUCTURAL Subtotal		637,731		105,250		404,734		203,162		150,125		325,091	1,826,093
J	2 Ground prep., burn (ac)	129.9	7,794					433	4,330					12,124
K	4 Seeding, broadcast, air (ac)	2,445.9	38,420											38,420
	6 Interseeding (ac)	6,494	64,940											64,940
L	7 Fertilize, estab. (ac)	6,494	10,823											10,823
	8 Fertilize, prod. (ac)	2,445.9	22,013			11,931	58,953							80,966
M	9 Water retention (ac)									763	7,630			7,630
N	11 Plant control burning (ac)	21,645	43,290							1,527	31,304			74,594
	12 Plant control, mech. (ac)	1,299	12,990					346	34,600			666	17,982	65,572
	13 Plant control, chem. (ac)					316	1,580	1,299	19,485			1,200	40,000	61,065
	14 Plant control, hand (ac)	320	8,000			7	1,400							9,400
O	15 Rodent control (ac)	1,083	758											758
P	16 Miscellaneous	--	46,753			--	3,509	--	9,524					59,786
	NONSTRUCTURAL Subtotal		255,781		0		65,442		67,939		38,934		57,982	486,078
	GRAND TOTAL		893,512		105,250		470,176		271,101		189,059		383,073	2,312,171

Table 2-5.--Amortized costs of proposed improvements in Planning Area 2

Type of improvement	Lifespan in years	Annual amortized cost						
		Bitterroot N.F.	Flathead N.F.	Kootenai N.F.	Lolo N.F.	Philipsburg R.D.	Lincoln R.D.	Planning Area total
		Dollars						
A Access	40	8,046	3,998	10,545	5,916	1,656	4,653	34,815
C Spring tanks	30	2,263		1,370	2,422	1,273	5,684	13,012
E Water transmission	30	2,254		12,730	460		4,172	19,616
F Dam & reservoir	30			389				389
G Other water develop	30				1,378			1,378
H Fence	25	56,898	7,288	18,181	11,585	13,432	20,566	127,949
STRUCTURAL Subtotal		69,461	11,286	43,215	21,760	16,362	35,075	197,159
J Ground preparation	5	2,056			1,142			3,198
K Seeding	30	10,964						10,964
L Fertilizer	3	13,204		23,705				36,909
M Water retention	30					809		809
N Plant control	15	8,451		392	7,111	4,116	7,623	27,693
O Rodent control	5	200						200
P Miscellaneous	1	51,428		3,860	10,476			65,764
NONSTRUCTURAL Subtotal		86,303		27,957	18,729	4,925	7,623	145,537
GRAND TOTAL		155,764	11,286	71,172	40,489	21,287	42,698	342,696

Table 2-6.--Additional grazing capacity and cost per additional AUM of proposed improvements in Planning Area 2

Category of improvement	Total additional AUM						
	Bitterroot N.F.	Flathead N.F.	Kootenai N.F.	Lolo N.F.	Philipsburg R.D.	Lincoln R.D.	Planning Area Total
	AUM's						
A Access	143		1,110	108	0	27	1,391
C Spring tanks	312		88	542	419	479	1,840
E Water transmission	221		1,265	225		399	2,110
F Dam & reservoir			327				327
G Other water				0			0
H Fence	1,092	356	2,034	628	6,848	320	11,278
STRUCTURAL Subtotal	1,768	359	4,824	1,503	7,268	1,225	16,946
J Ground preparation	30			0			30
K Seeding	139						139
L Fertilizer	126		1,293				1,419
M Water retention					610		610
N Plant control	559		179	589	534	373	2,234
O Rodent control	0						0
P Miscellaneous	0		0	95			95
NONSTRUCTURAL Subtotal	854		1,472	684	1,144	373	4,527
GRAND TOTAL	2,622	359	6,296	2,188	8,411	1,598	21,473

Category of improvement	Annual Amortized cost per additional AUM						
	Bitterroot N.F.	Flathead N.F.	Kootenai N.F.	Lolo N.F.	Philipsburg R.D.	Lincoln R.D.	Planning Area Total
	Dollars/AUM						
A Access	56.3	1332.7	9.5	54.8	----	172.3	25.0
C Spring tanks	7.2		15.6	4.5	3.0	11.9	7.1
E Water transmission	10.2		10.1	2.0		10.5	9.3
F Dam & reservoir			1.2				1.2
G Other water				----			----
H Fence	52.1	20.5	8.9	18.4	2.0	64.3	11.4
STRUCTURAL Subtotal	39.3	31.4	9.0	14.5	2.2	28.6	11.6
J Ground preparation	68.5			----			106.6
K Seeding	78.9						78.9
L Fertilizer	104.8		18.3				26.0
M Water retention					1.3		1.3
N Plant control	15.1		2.2	12.1	7.7	20.4	12.4
O Rodent control	-----						----
P Miscellaneous	-----		----	110.3			692.2
NONSTRUCTURAL Subtotal	100.8		19.0	27.4	4.3	20.4	32.2
GRAND TOTAL	59.4	31.4	11.3	18.5	2.5	26.7	16.0

PLANNING AREA 3: CENTRAL MONTANA

Planning Area 3 stretches 300 miles into Montana from its eastern border on the Continental Divide and about 400 miles from Wyoming on its southern edge north to Canada. It included a quarter-million people in 1970, the largest population of any Planning Area in the Region. Of the 6,400 ranches and farms in the Area, 11 percent had permits to graze on the four National Forests including the Beaverhead, Deerlodge, Helena, and Lewis and Clark. Selected descriptors of the Area are presented in table 3-1. Because they are physically more similar to the northwestern Montana National Forests, the Philipsburg and Lincoln Ranger Districts of the Deerlodge and Helena National Forests, respectively, are included in Planning Area 2.

More than one-fourth of the Region's grazing occurs in the broad valleys of Planning Area 3. With the exception of the grasslands of Planning Areas 5A and 5B, this Area has the smallest proportion of grazing under timber canopies. The Beaverhead National Forest dominates the Area in terms of grazing capacity and use; on this Forest, 43 percent of the Area's grazing capacity is concentrated on 43 percent the Area's grazing acreage.

Historical Improvements

In the past, the Area has received more than its proportionate share of improvements. A preponderance of the basic improvements required for any grazing--the construction of cattleguards, stock trails, and fencing--are concentrated here. This is also true of those improvements which characterize first-order efforts to improve utilization of forage--water transmission, ground preparation, rainwater retention, and plant control. At least in part, this past level of relatively heavy investment was no doubt due to the natural productivity of the land for grazing. This is partly reflected in the presence of the large number of privately financed cabins, barns, corrals, and loading chutes on the Beaverhead.

Table 3-1.--Selected descriptors of Planning Area 3, 1975

National Forest	Number of allotments	Number of permittees	Total net acreage	Net grazing acreage		Current grazing capacity AUM
				Total	Percent under timber canopy	
Beaverhead	199	221	2,132,209	639,110	23	174,349
Lewis and Clark	160	199	1,906,535	350,228	29	51,957
Deerlodge	94	134	787,300	293,829	41	39,119
Helena	78	132	639,313	210,188	67	33,624
Planning Area Total	531	686	5,465,357	1,493,355	35	299,049
Planning Area as percent of Northern Region	28	30	23	30	--	36

Replacement Costs and Productivity

We can generally trace the historical costs of making each of the existing improvements. However, for the purpose of making comparisons with proposals for future improvements, we have developed replacement costs by valuing on-the-ground improvements at today's average Planning Area costs, as determined in our survey. The results of these calculations are shown in table 3-2.

At today's prices, the existing range improvements in the Area represent an investment of almost $10 million. This represents about 43 percent of the replacement value of all investments that have been made in the Region. Since grazing capacity is only slightly more than one-quarter of the Region's total, this again suggests the Planning Area has a relatively highly developed range resource.

Because improvements have average useful lives of up to 40 years, it is necessary to amortize them over their lifespans to determine their average annual costs. The results are presented in the last column of table 3-2.

We can now calculate the productivity of current improvements by comparing annual replacement costs to annual AUM supported:

Grazing capacity	299,049 AUM
Total amortized cost of improvements	$1,131,794.00
Cost per AUM	$ 3.78

Table 3-2.--Calculation of total and amortized replacement costs of historical improvements in Planning Area 3

Type of improvement	Existing number	Replacement cost Per Unit	Replacement cost Total	Category replacement cost	Useful life	Amortized replacement cost
		Dollars		Dollars	Years	Dollars
A 1 Cattleguard	501	1,699	851,199			
2 Stock trail (mi)	189.4	1,043	197,544	1,053,993	40	107,780
3 Stock bridge	1	5,250	5,250			
B Tanks	8	1,296	10,368			
C Spring, tanks	1,072	593	635,696	649,943	30	68,946
D Wells	3	1,293	3,879			
E Water transmission (mi)	100.4	2,208	221,683			
F Dam & reservoir	95	1,273	120,935	413,118	30	43,823
G Other water dev.	47	1,500	70,500			
H Fence (mi)	3,155.3	1,879	5,928,809	5,928,809	25	653,168
I Cabin	11	5,000	55,000			
Barn	11	5,000	55,000			
Corral	30	1,000	30,000	145,000	10	23,598
Loading chute	6	500	3,000			
Dipping vats	4	500	2,000			
Structural Subtotal			8,190,863			897,315
J Ground preparation (ac)	522	13	6,786	6,786	5	1,790
K Seeding (ac)	777	10	7,770	7,770	30	824
L Fertilizer (ac)	522	10	5,220	5,220	3	2,099
M Water retention (ac)	2,566	10	25,660	25,660	30	2,722
N Plant control (ac)	172,690	10	1,726,900	1,726,900	15	227,041
O Rodent control (ac)	12	1	12	12	5	3
Nonstructural Subtotal			1,746,688			234,479
GRAND TOTAL			9,937,551			1,131,794

Table 3-[illegible] Planning Area total expenditures in the Northern Region by sources of funds

Source of funds	Expenditures: Dollars	Expenditures: percentage of expenditures in Region
Forest Service range improvements	2,714,000	66
Other Forest Service	1,090,800	43
Permittees	1,796,600	
ALL	5,601,400	57

Past Expenditures

Past expenditures in the Planning Area amounted to 57 percent of the Region's total investment program in developing grazing resources (table 3-3). This almost $6 million cumulative investment supports only 28 percent of the Region's total grazing capacity.

About one-third of all funds (in a combination of cash and labor) come from the permittees. Forest Service range improvement expenditures accounted for about one-half of the total, while other Forest Service expenditures account for the balance. There were considerable differences between National Forests with the Beaverhead and Deerlodge National Forests containing most of the investments.

Proposed Improvements

The 17 Ranger Districts in this Planning Area provided data for 54 allotments. The large number of allotments sampled reflects an increase in sampling intensity on the Beaverhead National Forest to six allotments per Ranger District. This was done to reflect the greater grazing opportunities on that Forest. The proposed improvements are presented by National Forest for the sampled allotments in appendix table A-3. Multiplying those figures by the appropriate sample expansion factors gives the estimated total investment opportunities in table 3-4.

The total improvements for the Planning Area are estimated to cost about $6 million, with over 60 percent of that money going to the Beaverhead. The largest expenditures are proposed for fencing, plant control, and water developments.

A comparison of the replacement costs of historical improvements to the costs of proposed improvements suggest some change in emphasis:

	Replacement cost of existing improvements (Percent)	*Cost of proposed improvements (Percent)*
Structural	82	72
Nonstructural	18	28

It is likely that, given the past substantial investments in structural improvements which still have long useful lives, more attractive opportunities exist in direct ground treatments.

Table 3-4.--Total proposed improvements and their costs for Planning Area 3

	Type of improvement	Beaverhead N.F.		Lewis & Clark N.F.		Deerlodge N.F. minus Philipsburg R.D.		Helena N.F. minus Lincoln R.D.		Planning Area
		Units	Cost	Units	Cost	Units	Cost	Units	Cost	Total Cost
			Dollars		Dollars		Dollars		Dollars	Dollars
A 1	Cattleguard	103	168,663	29	45,433	33	57,750	28	56,000	327,846
2	Stock trail (mi)	35.2	65,281	9.8	4,900	24.7	12,350	13.4	4,588	87,119
B 4	Trick tank							64	66,857	66,857
5	Pit tank			20	22,000					22,000
C 6	Spring, wood tank	84	81,415	265	137,408			101	64,272	283,095
7	Spring, metal tank	330	195,090	29	13,775	49	24,500	37	18,500	251,865
8	Spring, plastic tank					41	20,500			20,500
D 11	Well, pump	13	9,750	10	20,000					29,750
E 13	Water pipe (mi)	105.1	238,666	39.3	85,969	8.2	12,300			336,935
F 15	Dam & reservoir	13	26,000	20	16,000					42,000
G 16	Other water develop.	6	9,000							9,000
H 17	Fence, boundary (mi)	71.2	174,747	39.3	87,442	32.9	32,077			294,266
18	Fence, allot. boundary (mi)	240.6	461,159	159.6	245,489	8.2	32,800			739,448
19	Fence, interior (mi)	598.3	1,121,916	85.9	174,647	125.4	247,511	116.6	202,903	1,746,977
20	Fence, water source (mi)			11.8	19,175					19,175
I 22	Cabin			-----	22,099					22,099
STRUCTURAL Subtotal			2,551,687		894,337		439,788		433,120	4,318,932
J 1	Ground prep. plow (ac)			2,259	17,688			1,835	36,700	54,388
K 3	Seeding, broadcast, ground (ac)	12,587	38,805							38,805
5	Seeding, normal (ac)			982	9,820			1,835	9,175	18,995
6	Seeding, interseeding (ac)			1,277	11,787					11,787
L 7	Fertilize, estab. (ac)	6,468	213,444					1,835	64,225	277,669
8	Fertilize, prod. (ac)	40,424	168,164	1,277	49,113					217,277
N 11	Plant control, burning (ac)	43,820	184,482	2,946	19,653	822	9,866			214,001
13	Plant control, chem. (ac)	45,469	588,369	7,857	64,427	822	4,111	2,845	142,250	799,157
14	Plant control, hand (ac)	323	16,150							16,150
NONSTRUCTURAL Subtotal			1,209,414		172,488		13,977		252,350	1,648,229
GRAND TOTAL			3,761,101		1,066,825		453,765		685,470	5,967,161

Productivity of Proposed Improvements

Based on sample data we can associate categories of proposed improvements with increases in grazing capacity. Because grazing capacity is an annual figure, the costs of long-lived improvements must be amortized over their useful lives. The results of these calculations are shown in table 3-5.

Finally, we can calculate the annual amortized cost of producing one more AUM. From table 3-6 we see that the average cost per additional AUM for Planning Area 3 would be about $8.00. The cost would be least on the Deerlodge and greatest on the Beaverhead National Forest. One explanation for such differences is the Beaverhead National Forest has already invested in the more productive improvements: only the less productive ones remain.

3-5.--Amortized cost of proposed improvements in Planning Area 3

Type of improvement	Lifespan in years	Annual amortized costs				Planning Area
		Beaverhead	[illegible]	[illegible]	Helena	[illegible]
		Dollars				
A Access	40	23,923	5,147	7,168	6,196	42,434
B Rain tanks	30		2,334		9,214	[illegible]
C Spring tanks	30	29,331	16,037	4,773	8,780	58,921
D Wells	30	[illegible]	2,122			3,156
E Water transmission	30	25,318	9,120	1,305		35,743
F Dam and reservoir	30	2,758	1,697			4,455
G Other water develop.	30	[illegible]				955
H Fence	25	193,657	58,032	34,415	22,354	308,458
I Miscellaneous	10		3,596			3,596
STRUCTURAL Subtotal		276,976	[illegible]	47,661	46,544	[illegible]
J Ground preparation	[illegible]		4,666		9,681	14,347
K Seeding	30	4,116	2,292		973	7,381
L Fertilization	3	153,447	19,749		[illegible]	199,021
N Plant control	15	103,733	11,054	1,838	18,702	135,327
NONSTRUCTURAL Subtotal		261,296	37,761	1,838	55,181	356,076
GRAND TOTAL		538,272	135,856	49,499	101,725	825,342

Table 3-6.--Additional grazing capacity and cost per additional AUM of proposed improvements in Planning Area 3

Type of improvement		Total additional AUM				Planning Area Total	Annual amortized cost per additional AUM				Planning Area Total
		Beaverhead	Lewis & Clark	Deerlodge	Helena		Beaverhead	Lewis & Clark	Deerlodge	Helena	
		AUM					Dollars				
A	Access	400	16	1,151	189	1,756	59.8	321.7	6.2	32.8	24.2
B	Rain tanks		579		1,522	2,101		4.0		6.0	5.5
C	Spring tanks	10,315	13,725	4,341	2,376	30,757	2.8	1.2	1.1	3.7	1.9
D	Wells	776	49			825	1.3	43.3			3.8
E	Water transmission	7,541	2,977	617		11,135	3.4	3.1	2.1		3.2
F	Dam and reservoir	647	314			961	4.3	5.4			4.6
G	Other water develop.	0				0	----				----
H	Fence	9,206	11,400	9,295	2,687	32,588	21.0	5.1	3.7	8.3	9.5
I	Miscellaneous		0			0		----			----
STRUCTURAL Subtotal		28,885	29,060	15,404	6,774	80,123	9.6	3.4	3.1	6.9	5.9
J	Ground preparation		210		142	352		22.2		68.2	40.8
K	Seeding	385	342		142	869	10.7	6.7		6.8	8.5
L	Fertilization	3,366	106		142	3,614	45.6	186.3		181.9	55.1
N	Plant control	11,197	3,302	1,879	1,381	17,759	9.3	3.4	1.0	13.5	7.6
NONSTRUCTURAL Subtotal		14,948	3,960	1,879	1,807	22,594	17.5	9.5	1.0	30.5	15.8
GRAND TOTAL		43,833	33,020	17,283	8,581	102,717	12.3	4.1	2.9	11.8	8.0

PLANNING AREA 4: CENTRAL ROCKY MOUNTAINS

Planning Area 4 extends north and northwest from Yellowstone National Park into central Montana. The Area is characterized by rugged and steep forested slopes, extending from the Yellowstone River Valley to the Gallatin River drainage. The highest mountain in Montana, Granite Peak, is included. It is the smallest Planning Area in the Region, containing only the Gallatin National Forest and the Beartooth Ranger District of the Custer National Forest. In 1970, about 60,000 people lived within the Area. There were 2,647 ranches and farms; the 231 holders of permits for National Forest grazing were 10 percent of all permittees in the Region (table 4-1).

Historical Improvements

To develop the current modest grazing capacity in this rugged country, investments were required in providing access, water, fencing, and ground preparation (table 4-2). These kinds of improvements result in about 4 percent of the Region's total grazing capacity.

Replacement Costs and Productivity

At today's costs, these historical improvements would cost almost $750,000 to replace. When amortized over the useful life of the improvements, this cost averages about $84,000 annually. For the Planning Area, we can divide this annual replacement cost by grazing capacity to get a rough index of current productivity.

Grazing capacity	50,343 AUM
Total amortized costs of improvements	$83,853.00
Cost per AUM	$ 1.67

Past Expenditures

Past expenditures on the Gallatin National Forest and Beartooth Ranger District amounted to 5 percent of the Region's total. These are divided among contributors as shown in table 4-3. Almost 65 percent of these funds come from the Forest Service range improvement accounts with most of the rest coming from permittees.

Proposed Improvements

The seven Ranger Districts in this Area provided sample data for 13 allotments. The investment opportunities they propose are listed in appendix table A-4. These opportunities were projected for the entire Planning Area by using the sample expansion factors based on the ratio of sampled to total grazing capacities. The total physical improvements and their costs are displayed in table 4-4. The estimates total about $920,000 for the Gallatin National Forest and $46,000 for the Beartooth Ranger District. Such a package of investments will increase grazing capacities by almost 12,000 AUM, that is, by one-fourth.

Table 4-1.--Selected descriptors of Planning Area 4, 1975

Administrative unit	Number of allotments	Number of permittees	Total net acreage	Net grazing acreage: Total	Net grazing acreage: Percent under timber canopy	Current grazing capacity
						AUM
Gallatin N.F.	17	199	1,369,119	297,056	47	35,836
Beartooth R.D.	28	32	586,573	45,610	27	14,507
Planning Area Total	45	231	1,955,692	342,666	44	50,343
Planning Area as percent of Northern Region	10	10	8	7	--	4

Table 4-2.--Calculation of total and amortized replacement costs of historical improvements in Planning Area 4

Type of improvement	Existing number	Replacement cost: Per unit	Replacement cost: Total	Category replacement cost	Useful life	Amortized replacement cost
		Dollars	Dollars	Dollars	Years	Dollars
A 1 Cattleguard	14	1,112	15,568			
2 Stock trail (mi)	32.2	1,154	37,159	63,227	40	6,466
3 Stock bridge	2	5,250	10,500			
C Spring, tanks	155	398	61,690	61,690	30	6,544
E Water transmission (mi)	5.3	433	2,295	2,295	30	243
H Fence (mi)	319.8	1,713	547,817	547,817	25	60,352
I Cabin	2	5,000	10,000			
Barn	1	5,000	5,000	16,000	10	2,604
Corral	1	1,000	1,000			
Structural Subtotal			691,029			76,209
J Ground preparation (ac)	464	13	5,252	5,252	5	1,385
K Seeding (ac)	459	10	4,590	4,590	30	487
N Plant control (ac)	4,878	9	43,902	43,902	15	5,772
Nonstructural Subtotal			53,744			7,644
GRAND TOTAL			744,773			83,853

Table 4-3.--Historical expenditures for improvements in Planning Area 4 in total and as percent of total expenditures in the Northern Region by sources of funds

Source of funds	Expenditures: Dollars	Expenditures: As percent of expenditures in Region
Forest Service range improvement	287,800	7
Other Forest Service	8,000	Trace
Permittees	154,400	5
All	450,200	5

		Dollars			Cost Dollars
				[illegible]	[illegible]
S Pit tank					
C [illegible]	30	1,[illegible]		[illegible]	[illegible]
	20	9,000			[illegible]
[illegible]		1[illegible]			1[illegible]
H 18 Fence, allot. boundary (mi)		57,[illegible]			57,[illegible]
19 Fence, interior (mi)	293.1	[illegible]	17.7	17	53[illegible]
20 Fence, water source (mi)					
STRUCTURAL Subtotal		677,31[illegible]		700	72[illegible]
M 4 Seeding broadcast, air (ac)	4,471	44,71[illegible]			
[illegible]	4,719	32,[illegible]			[illegible]
N 11 Plant control, burn (ac)	1,987	9,935			
13 Plant control, chem.(ac)	14,40[illegible]	134,120			
14 Plant control, hand (ac)	994				
[illegible]					
NONSTRUCTURAL Subtotal		240,923			240,923
GRAND TOTAL		918,242			[illegible]

In Planning Area 4, a shift in emphasis between historical and proposed investments is apparent:

	[illegible] existing improvements (Percent)	Cost of proposed improvements (Percent)
Structural	93	73
Nonstructural	7	27

A much larger share of future expenditures will be for direct ground treatments. The Beartooth Ranger District continues to concentrate almost exclusively on structural improvements.

Productivity of Proposed Improvements

When the costs are amortized over the useful lives of the improvements, we find that this package of investments is roughly equivalent to an annual investment of $111,800. The underlying calculations are given in table 4-5.

As expected, the costs per AUM of nonstructural improvements as shown in table 4-6 are substantially higher than those of structures. Overall, production costs would be far lower on the Beartooth Ranger District than on the Gallatin. We hypothesize that this is probably due to a much less intensive development of grazing resources on the Beartooth: there is still a lot of undeveloped grazing capacity and water awaiting the construction of basic fences and access facilities. The average amortized cost per AUM for the Area is $9.60.

Table 4-5.--Amortized cost of proposed improvements in Planning Area 4

Type of improvement	Lifespan in years	Annual amortized cost		
		Gallatin N.F.	Beartooth R.D.	Planning Area Total
		Dollars		
A Access	40	2,147	1,718	3,865
B Rain tank	30	318		318
C Spring tanks	30	6,480	1,114	7,594
E Water transmission	30	1,370		1,370
G Other water	30		74	74
H Fence	25	57,356	1,950	59,306
STRUCTURAL Subtotal		67,671	4,856	72,527
K Seeding	30	4,743		4,743
L Fertilization	3	12,979		12,979
N Plant control	15	21,553		21,553
NONSTRUCTURAL Subtotal		39,275		39,275
GRAND TOTAL		106,946	4,856	111,802

Table 4-6.--Additional grazing capacity and cost per additional AUM of proposed improvement in Planning Area 4

Type of improvement	Total additional AUM			Annual amortized cost per additional AUM		
	Gallatin N.F.	Beartooth R.D.	Planning Area Total	Gallatin N.F.	Beartooth R.D.	Planning Area Total
	AUM			Dollars/AUM		
A Access	0	191	191	—	9.0	20.2
B Rain tank	79		79	4.0		4.0
C Spring tanks	1,977	375	2,352	3.3	3.0	3.2
E Water transmission	199		199	6.9		6.9
G Other water		35	35		2.1	2.1
H Fence	5,653	764	6,417	10.2	2.6	9.2
STRUCTURAL Subtotal	7,908	1,365	9,273	8.6	3.6	7.8
K Seeding	646		646	7.3		7.3
L Fertilization	894		894	14.5		14.5
N Plant control	825		825	26.1		26.1
NONSTRUCTURAL Subtotal	2,365		2,365	16.6		16.6
GRAND TOTAL	10,273	1,365	11,638	10.4	3.6	9.6

PLANNING AREAS 5A AND 5B: EASTERN MONTANA AND THE DAKOTAS

Planning Areas 5A and 5B are both administered by the Custer National Forest (the Beartooth Ranger District of the Custer is included in Planning Area 4). The Areas are administered separately because they are spread over a very large area; 5A includes the high plains of eastern Montana, and 5B the plains of the Dakotas. Area 5B includes the Cheyenne, Cedar River, and Little Missouri National Grasslands in North Dakota and the Grand River National Grasslands in South Dakota.

In 1970 there were about 135,200 people and 3,900 farms and ranches in Area 5A; there were half as many people in Area 5B, but 6,500 farms and ranches. That this is ranching country is again emphasized in the statistics in table 5-1. Together, the Planning Areas have 60 percent of the Region's grazing capacity on one-third of the Region's grazing acreage and only 7 percent of the total National Forest acreage. The key is simply the openness of the range; there is little timber. As a consequence, while on the average in the Region more than 4 acres are required to support one AUM, in areas 5A and 5B only 3 and 2 acres per AUM are required, respectively.

Table 5-1.--Selected descriptors of Planning Areas 5A and 5B, 1975

Ranger District	Number of allotments	Number of permittees	Total net acreage	Net grazing acreage		Grazing capacity
				Total	Percent under timber canopy	
						AUM
Ashland	27	41	207,507	156,066	36	58,300
Fort Howes	25	36	230,231	230,151	16	56,045
Sioux	64	84	162,889	120,519	35	50,200
Planning Area 5A Total	116	161	600,627	506,736	27	164,545
Planning Area as percent of Northern Region	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Grand River	77	131	161,927	154,649	[illegible]	63,903
Medora	266	262	524,452	523,282	[illegible]	222,945
McKenzie	206	[illegible]	501,000	375,900	3	206,130
Sheyenne	59	99	70,340	69,507	Trace	64,442
Planning Area 5B Total	608	686	1,257,719	1,123,338	1	557,420
Planning Area as percent of Northern Region	32	30	[illegible]	22	[illegible]	47

Table 5-2.--Calculation of total and amortized replacement costs of historical improvements in Planning Areas 5A and 5B

Type of improvement	Planning Area 5A					Planning Area 5B				
	Existing number	Replacement cost		Useful life	Amortized replacement cost	Existing number	Replacement cost		Useful life	Amortized replacement cost
		Per unit	Total				Per unit	Total		
		Dollars		Years	Dollars		Dollars		Years	Dollars
A Cattleguard	68	1,275	86,700	40	8,866	22	1,490	32,780	40	3,352
B Tanks	49	809	39,641			371	809	300,139		
C Spring, tanks	531	504	267,624	30	147,952	101	1,066	107,666	30	348,889
D Wells	110	9,886	1,087,460			347	8,303	2,881,141		
E Water transmission (mi)	10.0	3,099	30,990			17.1	4,640	79,344		
F Dam & Reservoir	337	1,500	505,500	30	57,077	505	1,180	595,900	30	74,061
G Other water develop.	10	157	1,570			146	157	22,922		
H Fence (mi)	946.5	1,870	1,769,955	30	187,756	1,235.4	1,875	2,316,375	30	245,720
I Corral	6	1,000	6,000	10	976	79	1,000	79,000	10	12,857
Structural Subtotal			3,795,440		402,627			6,415,267		684,879
J Ground prep (ac)										
K Seeding (ac)	727	2	1,454	30	154	891	2	1,782	30	189
L Fertilizer (ac)	127	9	1,143	3	460	470	4	1,880	3	756
M Plant control (ac)						40	12	480	25	53
Nonstructural Subtotal			2,597		614			4,142		998
GRAND TOTAL			3,798,037		403,241			6,419,409		685,877

Historical Improvements

Although grazing can take place on unimproved open range, some improvements are necessary for administrative control, to protect the range resource, and to increase grazing capacity. On the Custer National Forest minus the Beartooth Ranger District, as shown in table 5-2, most attention has been focused on developing water sources and fences. Most of the entire Region's water development investments have occurred here. In conjunction with this water development, fertilization and seeding have been important to increase forage production, and corrals have been built by the permittees to facilitate herd management.

Replacement Costs and Productivity

By applying current costs of construction and treatment to the historical improvements, we derived the replacement costs of those improvements in table 5-2. They total about $10 million with structures alone, particularly water developments and fencing, nearly accounting for the total. By amortizing these costs over the useful lives of the improvements, we learn that their average annual cost is over $1 million.

We can now calculate the productivity of these improvements by comparing their annual amortized costs to the (annual) AUM they support:

	Area 5A	Area 5B
Grazing capacity	164,545 AUM	557,420 AUM
Total amortized cost of improvements	$403,241.00	$685,877.00
Cost per AUM	$ 2.45	$ 1.23

These very low costs per AUM reflect the natural productivity of the Custer National Forest. The low costs in Area 5B may reflect failure to completely account for all range improvement practices on the Natural Grasslands prior to the Forest Service administration.

Past Expenditures

Expenditures related to range management on the Custer National Forest (excluding Beartooth Ranger District) over the years have totaled nearly $2.2 million (table 5-3).

Table 5-3.--Historical expenditures for improvements in Planning Areas 5A and 5B in total and as percent of total expenditures in the Northern Region by sources of funds

Source of funds	Expenditures	
	Dollars	As percent of expenditures in Region
		Percent
Forest Service range improvement	735,600	1
Other Forest Service	568,500	23
Permittees	865,200	27
ALL	2,169,300	15

Only on the Beaverhead National Forest has more money been spent. But because of less productive range there, the Custer has produced many more AUM per dollar spent. Permittees have contributed a substantial share of the improvements.

Proposed Improvements

A more intensive sample was made in Planning Areas 5A and 5B to reflect their greater share of the Region's grazing capacity. Proposed improvements are summarized for the 62 sampled allotments by each of the two Planning Areas in appendix table A-5. Multiplying these sample figures by the appropriate expansion factors gives the estimated total investment opportunities presented in table 5-4. About $12.6 million has been suggested for the two Areas combined.

Table 5-4.--Total proposed improvements and their costs for Planning Areas 5A and 5B

	Type of improvement	Planning Area 5A		Planning Area 5B	
		Units	Cost	Units	Cost
			Dollars		Dollars
A	1 Cattleguard	74	94,350	117	174,330
B	5 Pit tank			64	51,782
C	6 Spring, wood tank	107	100,544	6	6,000
	7 Spring, metal tank			35	38,500
	8 Spring, plastic tank	228	68,400	12	12,000
D	10 Well, windmill	48	280,615	23	11,500
	11 Well, pump	52	707,943	170	1,590,965
E	13 Water pipe (mi)	442.6	1,371,784	1,275.4	5,918,582
F	15 Dam & reservoir	22	33,000	88	103,840
H	17 Fence, boundary (mi)	148.7	289,439		
	18 Fence, allot. boundary (mi)	71.8	132,554	23.4	37,440
	19 Fence, interior (mi)	175.6	317,350	461.3	871,608
	20 Fence, water source (mi)	9.2	18,402		
	STRUCTURAL Subtotal		3,414,381		8,816,547
J	1 Ground prep. plow (ac)			11,709	35,127
	2 Ground prep. burn (ac)			6,499	6,759
K	5 Seeding, normal (ac)			11,709	23,418
	6 Seeding, interseeding (ac)			5,855	11,710
L	7 Fertilize, estab. (ac)			11,709	46,836
	8 Fertilize, prod. (ac)	1,840	16,560	22,247	77,197
M	10 Water retention (ac)			11,124	53,284
N	11 Plant control, burn (ac)	9,201	25,855		
	13 Plant control, chem. (ac)	736	8,832	2,225	27,812
O	15 Rodent control (ac)			937	2,342
	NONSTRUCTURAL Subtotal		51,247		284,485
	GRAND TOTAL		3,465,628		9,101,032

As has been true in the past, structures are seen as offering the major investment opportunities on both Planning Areas. There has been some shift toward investments in direct ground treatments:

	Replacement costs of existing improvements (Percent)	*Costs of proposed* (Percent)
Structural	99+	97
Nonstructural	Trace	3

A larger share of Area 5A's proposed expenditures (99 percent) would be used to build structures than in Area 5B (97 percent). As in the past, most attention remains focused on developing water resources and, most particularly, in pipes to spread the available water more evenly over the rangelands. Apparently, practices to improve the productivity of the range are not needed at this time, unlike the rest of the Region. That is, here the limiting factor appears to be water, not forage for most of the two Areas.

Productivity of Proposed Improvements

To estimate productivity of the proposed investments, we need in addition to the costs of those investments the increase in grazing capacity each will produce. Because our estimates of capacity are on an annual basis, we must also put investment costs on an annual basis. The results of these calculations are shown in table 5-5. Dividing the amortized investment costs by increases in capacity (table 5-6) provides the estimated cost per additional AUM.

Table 5-5.--Amortized cost of proposed improvements on Planning Areas 5A and 5B

Type of improvement	Life in years	Annual amortized costs	
		Area 5A	Area 5B
A [illegible]	40	9,648	17,827
B Rain tanks	30		5,493
C Spring tanks	30	17,921	5,993
D Wells	30	104,866	169,988
E Water transmission	30	145,518	627,840
F Dam and reservoir	30	3,501	10,015
H Fence	30	80,381	96,431
STRUCTURAL Subtotal		361,835	933,587
J Ground preparation			11,049
K Seeding	30		3,726
L Fertilizer	3	6,659	49,874
M Water retention	30		[illegible]
N Plant control	25	3,821	3,064
O Rodent control	[illegible]		618
NONSTRUCTURAL Subtotal		10,480	73,983
GRAND TOTAL		372,315	1,007,570

Table 5-6.--Additional grazing capacity and cost per additional AUM of proposed improvements in Planning Areas 5A and 5B

Type of improvements	Total additional AUM		Annual amortized cost per additional AUM	
	Planning Area 5A	Planning Area 5B	Planning Area 5A	Planning Area 5B
	AUM		Dollars/AUM	
A Access	37	0	260.8	--
B Rain tanks		4,174		1.3
C Spring tanks	1,583	3,519	11.3	1.7
D Wells	9,010	13,864	11.6	12.3
E Water transmission	14,796	83,867	9.8	7.5
F Dam and reservoir	1,564	6,364	2.2	1.7
H Fence	13,728	37,019	5.9	2.6
STRUCTURAL Subtotal	40,718	148,807	8.9	6.3
J Ground preparation		4,918		2.2
K Seeding		2,681		1.4
L Fertilizer	328	7,716	20.3	6.5
M Water retention		1,674		3.4
N Plant control	1,115	140	3.4	21.9
O Rodent control		0		--
NONSTRUCTURAL Subtotal	1,443	17,129	7.3	4.3
GRAND TOTAL	42,161	165,936	8.8	6.1

Contrary to other Planning Areas, the costs of increasing capacity through ground treatments is lower than through building structures. It is worth reemphasizing, though that some combination of both kinds of improvements is more productive than just financing one kind, once the intensity of management has gone beyond just using nature's bounty. The total costs per AUM on these Planning Units are $8.8 per AUM on Area 5A, and $6.1 per AUM on Area 5B.

SUMMARY FOR NORTHERN REGION

For the entire Northern Region, opportunities now exist to invest $23,320,000 in increasing the annual grazing capacity on the National Forests by more than 360,000 AUM. Historical investments in ground (nonstructural) treatments and in structures now existing are estimated to cost $23,250,000 at today's prices. The current annual grazing capacity is about 1,175,000 AUM.

Proposed and Historical Improvements

Because we have valued all physical improvements at current prices, it is possible to compare those improvements in terms of investment costs. The costs of all improvements by category and Planning Area are summarized in tables S-1 and S-2.

Structural Improvements

Although the total proposed and historical costs of structural improvements are roughly the same, significant differences in the elements of these totals can be seen by examining individual categories of improvements. The last column of table S-1 provides a rough index of shifting priorities. Most notably, far less emphasis is placed on proposed fencing and developing water resources, while expenditures for water transmission would be greatly increased. This is especially apparent on the easternmost Planning Areas, 5A and 5B, which are, essentially, the Custer National Forest. In contrast, fencing would receive a substantially increased share of investment funds on the western, forest-dominated Planning Areas.

Comparing Planning Areas indicates that most Planning Areas would like to increase or at least maintain past investment levels for structural improvements. In contrast, in Planning Area 3, dominated by the Beaverhead National Forest, most structures are apparently already in place and relatively little additional construction has been proposed.

Nonstructural Improvements

The situation is quite different when proposed expenditures for directly increasing forage production are considered. For nearly every category of improvement and for all Planning Areas except one, substantial increases in investment have been proposed (table S-2). Perhaps twice as many acres would be treated in the future as previously, with emphasis on plant control and fertilization in the east and on seeding, fertilization, and plant control in the west. As was true for structural improvements, Planning Area 3 has proposed the lowest level of new investments relative to old investments.

Table S-1.--Current costs of providing historical and proposed structural improvements (top number historical, bottom number proposed), by Planning Area and Region (Dollars)

Category of improvement		Planning Area: N. Idaho 1	W. Montana 2	Cent. Montana 3	Cent. Rocky Mt. 4	E. Montana 5A[1]	Dakotas 5B[1]	Northern Region: Total costs	Proposed as proportion of historical
A. Access	H	168,823	291,704	1,053,993	63,227	86,700	32,780	1,697,227	0.8
	P	271,631	340,463	414,965	37,800	94,350	174,330	1,333,539	
B. Rain tanks	H	7,800	1,300	10,368	0	39,641	300,139	359,248	0.5
	P	0	0	108,857	3,000	0	51,782	163,639	
C. Spring development	H	104,976	98,406	635,696	61,690	267,624	107,666	1,276,058	0.8
	P	28,208	122,661	555,460	71,590	168,944	56,500	1,003,363	
D. Wells	H	0	1,167	3,879	0	1,087,460	2,881,141	3,973,647	0.7
	P	0	0	29,750	0	988,558	1,602,465	2,620,773	
E. Water transmission	H	3,571	6,812	221,683	2,295	30,990	79,344	344,695	22.7
	P	0	184,916	336,935	12,913	1,371,784	5,918,582	7,825,130	
F. Dams and reservoirs	H	27,020	3,663	120,935	0	505,500	595,900	1,253,018	0.2
	P	16,400	3,667	42,000	0	33,000	103,840	198,907	
G. Other water developments	H	314	80	70,500	0	1,570	22,922	95,386	0.3
	P	3,454	12,990	9,000	700	0	0	26,144	
H. Fence	H	203,994	1,099,785	5,928,809	547,817	1,769,955	2,316,375	11,866,735	0.6
	P	346,528	1,161,396	2,799,866	538,325	757,745	909,048	6,512,908	
I. Other structural[2]	H	200,500	27,500	145,000	16,000	6,000	79,000	474,000	0.1
	P	46,125	0	22,099	0	0	0	68,224	
Total structural costs	H	716,998	1,530,417	8,190,863	691,029	3,795,440	6,415,267	21,340,014	
	P	712,346	1,826,093	4,318,932	664,328	3,414,381	8,816,547	19,752,627	
Proposed as proportion of historical		1.0	1.2	0.5	1.0	0.9	1.4	0.9	

1/ Combined 5A and 5B make up Custer National Forest historical improvements excluding Beartooth Ranger District from Planning Area 4.
2/ Historical improvements consist of cabins, barns, corrals, and loading chutes, all totally privately financed. Few such new structures are proposed; most proposals are for miscellaneous structural improvements not specifically identified elsewhere.

Table S-2.--Current costs of providing historical and proposed nonstructural improvements (top number historical, bottom number proposed), by Planning Area and Region (Dollars)

Category of improvement		Planning Area						Northern Region	
		N. Idaho 1	W. Montana 2	Cent. Montana 3	Cent. Rocky Mt. 4	E. Montana 5A[1]	Dakotas 5B[1]	Total costs	Proposed as proportion of historical
J. Ground preparation	H	2,500	0	6,786	5,252	0	0	14,538	7.6
	P	1,600	12,124	54,388	0	0	41,886	109,998	
K. Seeding	H	3,120	56,328	7,770	4,590	1,454	1,782	75,044	5.4
	P	152,060	103,360	69,587	44,710	0	35,126	404,849	
L. Fertilization	H	529	28	5,220	0	1,143	1,880	8,880	115.1
	P	253,549	91,789	494,946	32,278	16,560	124,033	1,013,155	
M. Water retention	H	0	1,040	25,660	0	0	0	26,700	2.3
	P	0	7,630	0	0	0	53,284	60,914	
N. Plant control	H	13,011	4,690	1,726,803	43,902	0	484	1,787,949	1.
	P	894,960	210,681	1,029,308	163,935	24,667	27,812	1,961,333	
O. Rodent control	H	0	120	12	0	0	0	132	62.4
	P	5,140	758	0	0	0	1,342	1,240	
P. Miscellaneous nonstructural	H	0	0	0	0	0	0	0	---
	P	68,845	53,760	0	700	0	0	214,431	
Total nonstructural	H	21,160	62,326	1,772,241	53,744	2,597	4,146	1,916,197	
	P	861,253	430,342	1,648,229	241,623	51,227	284,483	3,771,157	
Proposed as proportion of historical		41.4	17.6	18.9	8.9	19.7	68.7	1.9	

1/ See footnote on table S-1.

Relative Productivity of Improvements

When nonstructural and structural improvements are combined, the kinds of differences between historical and proposed improvements noted above again can be seen (table S-3) Most historical and proposed improvements are associated with Planning Areas 3, 5A, and 5B, essentially the Beaverhead and Custer National Forests. The Beaverhead is unique, for while its proportion of total proposed expenditures would be less than its proportion of historical expenditures, its share of total added capacity would be greater than its share of current capacity. The explanation is that past expenditures have been far more intensive relative to grazing capacity than anywhere else in the Region. Given those improvements, relatively small further investments would be quite productive.

It is apparent that Planning Areas 1, 2, and 4 contribute relatively little to Regionwide grazing capacity. As a reflection of relatively modest natural productivity and past investments and short seasons when grazing is possible, the proposed substantial increases in expenditures would not contribute proportionally to the expected total increase in the Region's grazing capacity.

Just looking at the total costs of improvements can be misleading because these totals are dominated by expenditures for structures which have long, useful lives. When the costs of long-lived improvements are appropriately amortized, we can determine the average cost of producing one AUM, as summarized in table S-4.

A comparison of the last two columns shows that the average cost per AUM in the past has been less than the average cost per AUM for the proposed capacity increase. This is to be expected, for, to this point, reliance has been much greater on nature's bounty; to a large extent, undeveloped grass and water resources have determined capacity. Increasing that capacity requires a capital-intensive program of development which is more expensive per AUM produced.

With two exceptions, the additional cost of adding one AUM decreases from west to east within the Region. This reflects the natural productivity and forest cover of the land. Planning Area 3 does not fit because of exceptionally high levels of investment in the past, as mentioned earlier.

Table S-3.--Distribution of current and proposed grazing capacities and proportion of current costs for historical and proposed range improvements by Planning Areas

Planning Area	Historical			Proposed		
	Current capacity	Percent of current capacity	Percent of costs of improvements	Additional capacity	Percent of additional capacity	Percent of costs of improvements
	AUM	Percent	Percent	AUM	Percent	Percent
1	52,767	4.5	3.2	20,650	5.7	6.7
2	50,838	4.3	6.8	21,473	5.9	9.9
3	299,049	25.4	42.8	102,717	28.2	25.6
4	50,343	4.3	3.2	11,638	3.2	3.9
5A	164,545	14.0	16.3	42,161	11.6	14.9
5B	557,420	47.5	27.6	165,936	45.5	39.0
Northern Region	1,174,962	100.0	100.0	364,575	100.0	100.0

Table S-4.--Additional amortized cost of structural and nonstructural improvements per additional AUM and average amortized proposed and replacement cost per AUM by Planning Area (Dollars)

Planning Area	Additional Cost per AUM			Average Cost per AUM	
	Proposed improvements			Historical improvements	Proposed improvements
	Structural improvements	Nonstructural improvements	Total	Total	Total
1	7.1	24.1	15.0	1.7	5.4
2	11.6	32.2	16.0	3.4	7.2
3	5.9	15.8	8.0	3.8	4.9
4	7.8	16.6	9.6	1.7	3.2
5A	8.9	7.3	8.8	2.4	3.8
5B	6.3	4.3	6.1	1.2	2.3
Northern Region	6.9	14.9	8.1	2.2	3.6

An Economic Supply Curve

Based on the information presented above by Planning Area, we can now develop approximate relationships between additional grazing capacities that might be produced in the Region and additional costs.

If we assume that the least-cost Planning Area will be entirely funded as a unit before the next Area is funded, the relationship would be as in table S-5.

Because local considerations rule out the chance that Planning Areas would, in fact, be entirely funded one at a time, this approach is not satisfactory. Such a level of aggregation also hides the variation in the productivity of particular kinds of investments within Planning Areas.

An approach more demanding of information is to establish the relationships between additional grazing capacity and specific kinds of investments and their costs, regardless of the administrative unit in which they would occur. This is the approach taken in table S-6.

We do not feel it would be useful at this point to further analyze our data in an attempt to provide a guide for specific investment decisions, though such a guide is sorely needed. Our information simply is not good enough. However, the data in table S-6 do strongly suggest the categories of investments, by Planning Areas, that most demand further investigation.

An approximation of a standard economic supply curve for the Region is shown in figure 2. Based on table S-6, this curve summarizes the costs of increasing grazing capacity by successive increments. It suggests, for example, that if the value of an

Table S-5.--Relationships between additional grazing capacity and costs, assuming Planning Areas are funded as units

Planning Area	Amortized cost per additional AUM	Increase in grazing capacity	Total additional grazing capacity	Total amortized cost of additional grazing capacity
	Dollars	AUM	AUM	Dollars
5B	6.1	165,936	165,936	1,007,570
3	8.0	102,717	268,653	1,832,912
5A	8.2	42,161	310,814	2,205,227
4	9.6	11,638	322,452	2,317,029
1	15.0	20,650	343,102	2,626,715
2	16.0	21,473	364,575	2,969,411

Table S-6.--Relationships between additional grazing capacity and costs, assuming categories of improvements within Planning Areas are funded as units

Planning Area	Improvement Category	Amortized cost per additional AUM	Increase in grazing capacity	Total additional grazing capacity	Current cost of additional grazing capacity	Total current cost of additional grazing capacity
		Dollars	AUM	AUM	Dollars	Dollars
5B	Nonstructural	4.3	17,129	17,129	284,485	284,485
3	Structural	5.9	80,123	97,252	4,318,932	4,603,417
5B	Structural	6.3	148,807	246,059	8,816,547	13,419,964
1	Structural	7.1	11,061	257,120	712,346	14,132,310
5A	Nonstructural	7.3	1,443	258,563	51,247	14,183,557
4	Structural	7.8	9,273	267,836	664,328	14,847,885
5A	Structural	8.9	40,718	308,554	3,414,381	18,262,266
2	Structural	11.6	16,946	325,500	1,826,093	20,088,359
3	Nonstructural	15.8	22,594	348,094	1,648,229	21,736,588
4	Nonstructural	16.6	2,365	350,459	241,623	21,978,211
1	Nonstructural	24.1	9,589	360,048	861,254	22,839,465
2	Nonstructural	32.2	4,527	364,575	486,078	23,325,543

AUM produced on National Forests in the Region is in the neighborhood of $4.00,[4] no expansion of grazing capacity would be warranted. On the other hand, if an AUM were valued at $14.60,[5] then about 325,500 AUM more could be efficiently produced. Supply curves for specific Planning Areas, which could better consider local conditions, were not constructed because of the reservations expressed above about the basic study data.

It is likely that the supply curve shown in figure 2 is slightly low, that is, actual costs for given additional grazing capacities in reality would be somewhat higher. The costs derived in this study omit the Forest Service costs for general management and administration.

[4] Based on private lease rates adjusted to reflect differences in operating and harvesting costs as calculated by Sassaman and Fight (1975, p. 187).

[5] Based on market value of beef minus costs from the hoof to the market as calculated by USDA Forest Service (1976, p. BBB-5).

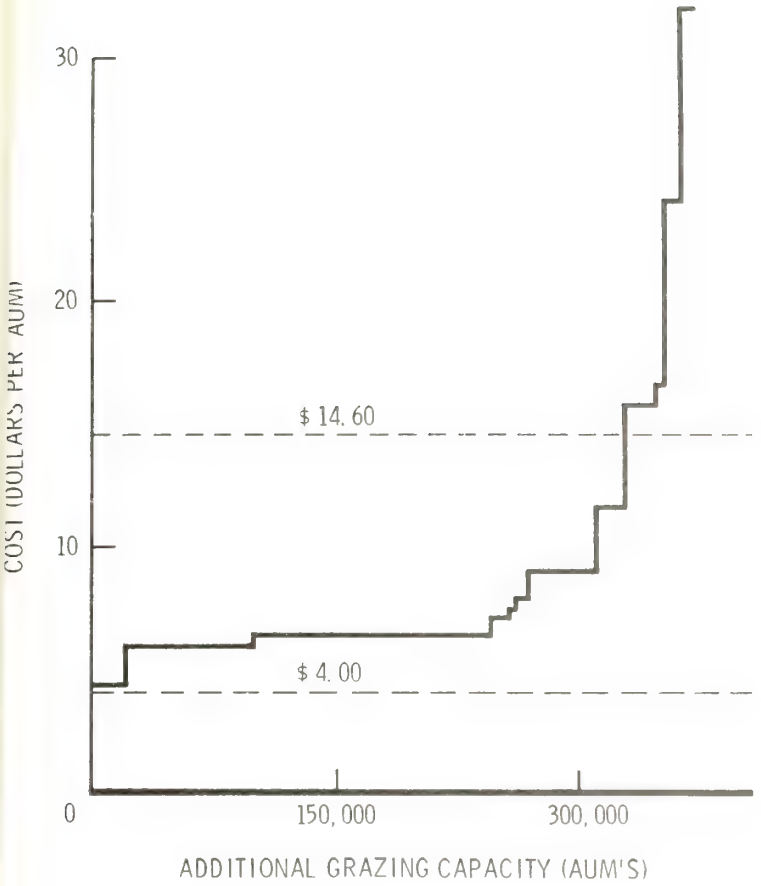

Figure 1.--Economic supply curve for grazing in the Northern Region.

Public Versus Private Funding

Aside from information concerning the values and development costs associated with potential improvements, at least one other issue is critical in determining the desirable level and composition of investments in range improvements on the National Forests. This is the source of investment funds, for some would come from Forest Service appropriations and some from the individual permittees.

By administrative directive the Forest Service must evaluate investments in range development at a 10 percent rate of return while the returns required by permittees for investments to be desirable vary a good deal, but are essentially unknown. In the present study, because only those improvements which would be attractive to the permittees were proposed, we assume they would earn a satisfactory return on their investments. If that is the case, and the economic attractiveness of the total investment is of concern, then the economic supply curve given above is useful. If just the perspective of the Forest Service is considered, the "correct" economic supply curve would be somewhat different, depending upon the cost borne by the Forest Service for specific categories of investment in specific Planning Areas.

The Forest Service proportions of historical and proposed expenditures are presented in table S-7. About two-thirds of all range improvement costs in both instances have been paid by the Forest Service. To the extent that the proportions funded by the permittees are expressions of local economic importance, those proportions also provide a crude index of local concern.

Table S-7.--Proportion of historical and proposed range improvement costs funded by the Forest Service (percent)

Planning Area	Historical proportion	Proposed proportion
1	84	82
2	67	72
3	68	69
4	66	55
5A	77	52
5B	52	72
Northern Region	68	68

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APPENDIX A
Tables A-1 through A-6

Appendix Table A-1.--Proposed improvements, average unit costs, and expected additional grazing capacity for sampled allotments by National Forests in Planning Area 1.

Type of Improvement	Clearwater N.F. cost/ unit	Clearwater N.F. units	Clearwater N.F. added capacity	Panhandle N.F. cost/ unit	Panhandle N.F. units	Panhandle N.F. added capacity	Nezperce N.F. cost/ unit	Nezperce N.F. units	Nezperce N.F. added capacity
STRUCTURAL	($)		AUM	($)		AUM	($)		AUM
A. 1	2,556	9		2,250	4	20	995	31	
2	417	6	82				1,000	1	420
3							5,250	2	
C. 7	500	7	58				478	9	1,037
F.15	1,200	4	58				200	1	96
G.16	157	7	37						
H.17	2,296	2.7		1,500	2.0	127	1,000	10.0	
18	1,543	7.0	200	1,667	3.0		1,182	5.5	790
19	827	15.0		1,574	4.7		925	35.5	
20	5,000	1.0							
I.22	5,000	--	6	11,000	--	0			
NONSTRUCTURAL									
J. 1	100	5	7						
K. 3	40	5					15	20	
4	5	2,000	117				20	1,400	966
6							10	200	
L. 7	10	5	255						259
8	17	2,800					52	500	
N.11	200	15							
12							50	200	
13	16	1,305	84	35	657	161	30	1,420	647
14	50	300							
O.15	10	100	2				20	25	4
Q.16	14,000	--	62	3,500	--	23			

Appendix Table A-2.--Improvements proposed for sampled allotments, average unit costs, and expected additional grazing capacity in Planning Area 2

Type of improvement	Bitterroot N.F.			Flathead N.F.		
	Cost/ unit	Units	Added capacity	Cost/ unit	Units	Added capacity
	Dollars		AUM	Dollars		AUM
STRUCTURAL						
A 1	1,762.50	8	33	1,700	8	1
2	1,000	4				
3						
C 6						
7	266.67	18	72			
E 13	1,250	2	51			
14	2,500	1				
F 15						
G 16						
H 17	2,000	5	252	1,890	5	122
18	3,186.21	14.5		1,890	7	
19	2,514.29	24.5				
20	2,000	.75				
NONSTRUCTURAL						
J 2	60	30	7			
K 4	15.71	565	32			
6	10	1,500				
L 7	1.67	1,500	29			
8	9	565				
M 9						
N 11	2	5,000	129			
12	10	300				
13						
14	25	74				
O 15	.70	250	0			
P 16						

Appendix Table A-2.--Continued

Type of improvement	Kootenai N.F. Cost/unit (Dollars)	Kootenai N.F. Units	Kootenai N.F. Added capacity (AUM)	Lolo N.F. Cost/unit (Dollars)	Lolo N.F. Units	Lolo N.F. Added capacity (AUM)
STRUCTURAL						
A 1	876.79	14		1,205.27	11	25
2	40	1	316			
3	15,000	1				
C 6	300	1	25			
7	468.57	7		407.69	13	125
E 13				333.33	3	52
14	30,000	1	360			
F 15	333.33	3	93			
G 16				300	10	0
H 17				1,725	4	
18	2,118.75	16		1,225	4	
19	2,151.80	6.1	579	1,435.29	8.5	145
20	300	.1		1,000	.3	
NONSTRUCTURAL						
J 2				10	100	0
K 4						
6						
L 7						
8	4.94	3,400	368			
M 9						
N 11						
12				100	80	
13	5	90		15	300	136
14	200	2	51			
O 15						
P 16			0			22

Appendix Table A-2.--Continued

Type of improvement	Philipsburg R.D.			Lincoln R.D.		
	Cost/ unit	Units	Added capacity	Cost/ unit	Units	Added capacity
	Dollars		AUM	Dollars		AUM
STRUCTURAL						
A 1	1,080	2	0	1,500	1	2
2				2,000	1	
3						
C 6				833.33	3	36
7	800	2	55	750	2	
E 13				4,916.67	.6	30
14						
F 15						
G 16						
H 17						
18	3,000	1	898	2,500	2	24
19	3,250	4		2,250	4	
20						
NONSTRUCTURAL						
J 2						
K 4						
6						
L 7						
8						
M 9	10	100	80			
N 11	20.50	200	70			
12				27	50	28
13				33.33	90	
14						
O 15						
P 16						

Appendix Table A-3.--Improvements proposed for sampled allotments, average unit costs, and expected additional grazing capacity by National Forests in Planning Area 3.

Type of improvement	Beaverhead N.F.			Lewis and Clark N.F.		
	Cost/ unit	Units	Added capacity	Cost/ unit	Units	Added capacity
	Dollars	Number	AUM	Dollars	Number	AUM
STRUCTURAL						
A 1	1,637.50	16	62	1,566.66	3	2
2	1,854.55	5.5		500	1	
B 4				1,100.00	2	59
5						
C 6	969.23	13	1,595	518.52	27	1,397
7	591.18	51		475.00	3	
8						
D 11	750	2	120	2,000.00	1	5
E 13	2,270.77	16.25	1,166	2,187.50	4	303
F 15	2,000.00	2	100	800.00	2	32
G 16	1,500.00	1	0			
H 17	2,454.55	11	1,423	2,225.00	4	1,161
18	1,916.67	37.2		1,538.15	16.25	
19	1,875.14	92.5		2,033.14	8.75	
20				1,625.00	1.2	
I 22				2,250.00	--	0
NONSTRUCTURAL						
J 1				7.83	230	21
3						
K 3	15.00	400	60			
5				10.00	100	35
6				9.23	130	
L 7	33.00	1,000	520			
8	4.16	6,250		38.46	130	11
N 11	4.21	6,775	1,731	6.67	300	336
13	12.94	7,030		8.20	800	
14	50	50				

Appendix Table A-3.--Continued

Type of improvement	Deerlodge N.F. Cost/ unit	Deerlodge N.F. Units	Deerlodge N.F. Added capacity	Helena N.F. Cost/ unit	Helena N.F. Units	Helena N.F. Added capacity
	Dollars	Number	AUM	Dollars	Number	AUM
STRUCTURAL						
A 1	1,750.00	4	140	2,000.00	3	21
2	500.00	3		333.33	1.5	
B 4						
5				1,357.14	7	166
C 6				636.36	11	259
7	500.00	6	528	500.00	4	
8	500.00	5				
D 11						
E 13	1,500.00	1	75			
F 15						
G 16						
H 17	975.00	4	1131			
18	4,000.00	1				
19	1,973.77	15.25		1,740.16	12.7	292
20						
I 22						
NONSTRUCTURAL						
J 1				20.00	200	15
3						
K 3						
5				5.00	200	15
6						
L 7				35.00	200	15
8						
N 11	12.00	100	228			
13	5.00	100		50.00	310	150
14						

Appendix Table A-4.--Improvements proposed for sampled allotments, average, unit costs and expected additional grazing capacity, in Planning Area 4

Type of improvement	Gallatin N.F.			Beartooth R.D.		
	Cost/ unit	Units	Added capacity	Cost/ unit	Units	Added capacity
	Dollars	Number	AUM	Dollars	Number	AUM
STRUCTURAL						
A 1	1,050	2	--	1,200	2	27
B 5	300	1	8			
C 6	400	3	199	500	3	53
7	404.5	11				
8	250	2				
E 13	433.33	3	20			
G 16				100	1	5
H 18	1,546.67	3.75	569	1,000	2.5	108
19	1,776.27	29.5				
20	2,000	.05				
NONSTRUCTURAL						
K 4	10	450	65			
L 8	6.84	475	90			
N 11	5	200	83			
13	9.31	1,450				
14	20	100				

	Type of	Area 5				
A	1	1,275				3
	2					713
	3					601
	4	300				
C	12					
	13					14,325
F	19	1				1,097
H	25			3,700		6,313
	26					
J	1				1,110	
	2					
K	5				1,000	
	6					
L	7					1,318
	8			89		
M	10					286
N	11				380	
	13			303		
O	17				100	

Appendix Table A-6.--Interest factors and average useful lives of range improvements in the Northern Region

Type of improvement	Planning Areas 1-4		Planning Areas 5A and 5B	
	10% Interest factor	Years	10% Interest factor	Years
STRUCTURAL				
A. Access[1/]	0.1023	40	0.1023	40
B-G. Water developments	.1061	30	.1061	30
H. Fences	.1102	25	.1061	30
I. Other structural[2/]	.1628	10	.1628	10
NONSTRUCTURAL				
J. Ground preparation[3/]	.2638	5	.2638	5
K. Seeding	.1061	30	.1061	30
L. Fertilization	.4021	3	.4021	3
M. Water retention	.1061	30	.1061	30
N. Plant control	.1315	15	.1102	25
O. Rodent control	.2638	5	.2638	5
P. Other nonstructural[4/]	1.1000	1	1.1000	1

Sources: Interest factors - Lundgren (1971, p. 115-128) and years - Duran and Kaiser (1972) except:

1/ Northern Region experience.
2/ Primarily private investments; maximum Forest Service permit is 10 years; usually depreciated for tax purposes within 10 years.
3/ Nearly all prescribed burning.
4/ Based on specific improvements indicated in sample.

APPENDIX B
Definitions

Structural Improvements

A. 1. Cattleguard--A device installed on roads, that livestock cannot cross, while vehicular traffic can pass over. It is usually made of rails, steel tubing, or lumber spaced to discourage livestock. Its size varies with the width of the road, and fences are joined to both sides.

A. 2. Stock Trail--A designated road, usually dirt, made for access to livestock i an area. Logging roads or other roads are often used for this purpose by permittees.

A. 3. Stock Bridge--An underpass or overpass for the cattle to move from one location to another without crossing a busy highway, railroad right-of-way, or stream. It may also be built to avoid mined areas or natural hazards.

B. 4. Trick Tank--Rainwater collecting device in arid and semiarid ranges.

B. 5. Pit Tank--Similar to the trick tank, collecting surface water in natural depressions, waterways, etc., for range livestock.

C. 6, 7, & 8. Spring Development--Spring development with different tanks made out of wood, metal, and plastic. Spring water fills the tank over a few days, providing th livestock with ample water during the grazing season.

D. 9 through 12. Well Development--Artesian, windmill, electric pump, etc., any device, which provides underground water supplies for the livestock grazing on the rang

E. 13 & 14. Water Transmission--Water transmission by pipeline or by ditch is closely related to well development. It avoids livestock travel to and from arid and semiarid ranges to the water source.

F. 15. Dam and Reservoir--An earthen dam constructed at low cost, in natural depre sions or small watercourses. Most of these reservoirs cover less than an acre.

G. 16. Other Water Developments--Devices or man-made improvements (other than reservoirs) to provide water for livestock.

H. 17 through 21. Fence--Fencing defines an area to be grazed by a certain number of livestock. Fenced areas may be protected, used in a cycle of rest and rotation, or used to protect water sources and right-of-ways. Boundaries of a National Forest and allotments may also be delineated by fences.

I. 22. Others, Not Listed--Structural improvements in this category are mainly built by permittees--cabins, corrals, loading chutes, and barns. None of these items was reported as a proposed improvement in this grazing survey.

Nonstructural Improvements

J. 1. Ground Preparation - Plowing--Preparation for seeding often requires the removal of certain vegetation and loosening the soil.

J. 2. Ground Preparation - Burning--Burning undesirable vegetation on the range before seeding is sometimes done to promote seed germination and early growth.

K. 3 through 6. Seeding--Different kinds of seeding may be used to establish a goo range at different costs. Ground seeding may cost more than air seeding, if large area are to be covered. Normal seeding with drills is also expensive. Interseeding differe species into native grass may have the same effect and cost less.

L. 7 & 8. Fertilization--Two different kinds of fertilization are listed in this survey, one being used with the seeding to establish the range, while the other is used to increase growth of existing forage.

M. 9 & 10. Water Retention--Using the contours of the land aided by ditches, pits, etc., snowmelt or rainwater can be spread over a large area. Pitting is closely relate to the rainwater collecting device in Group b, but natural depressions are used to collect the water.

N. 11 through 14. Plant Control--Removal of undesirable vegetation from ranges and seeding them with native or other forage plants is the main device to increase forage for livestock in semiarid country. Plant control may include removal of selected vegetation, removal of brush, and controlling poisonous plants.

O. 15. Poisoning, Rodent Control--Rodents reduce vegetation and create hazards for livestock. Poisoning may remove the rodents.

Horvath, Joseph C., Dennis L. Schweitzer, and Enoch F. Bell.
1978. Grazing on National Forest System lands: costs of increasing capacity in the Northern Region. USDA For. Serv. Res. Pap. INT-215, 56 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Feasibility of increasing grazing capacity through additional range improvements was investigated in the Northern Region of the USDA Forest Service. Sample grazing allotments on representative Ranger Districts were evaluated by questionnaire. Results of the survey included estimates of additional livestock that could be grazed, cost of additional improvements, and value of existing improvements.

KEYWORDS: range improvements, grazing capacity, range management, costs.

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A SEARCH FOR PHYTOTOXINS INFLUENCING GERMINATION AND EARLY GROWTH OF PONDEROSA PINE

RICK G. KELSEY
MICHAEL G. HARRINGTON

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This report was prepared as a cooperative project of the Intermountain Forest and Range Experiment Station and the Wood Chemistry Laboratory, University of Montana, Missoula.

RESEARCH SUMMARY

A series of laboratory and field experiments were conducted to determine if mature ponderosa pines produce a substance (phytotoxin) that inhibits the germination and growth of seedlings directly under the tree crown.

Neither live nor dead materials collected from ponderosa pines produced either volatile or water-soluble phytotoxins that drastically inhibited germination of seeds or growth of seedlings.

Seeds overwintering beneath the canopy of mature pines, or planted in soils collected there, showed reduced germination. Exact cause of the reduction was not determined. If weak phytotoxins were responsible, they did not inhibit growth of seedlings that germinated.

CONTENTS

	Page
INTRODUCTION	1
LITERATURE REVIEW	2
EXPERIMENTAL STUDIES AND RESULTS	4
Seed Source and Preparation	4
Tests for Volatile Inhibitors	4
Tests for Water Soluble Toxins	5
Toxicity of Plant Leachates on Soils	10
Field Soil Bioassay	13
Seedbed Effect on Germination	15
ALLELOPATHY AND MYCORRHIZAE	19
SUMMARY	19
CONCLUSIONS	20
PUBLICATIONS CITED	21

INTRODUCTION

Pinus ponderosa Laws. is found throughout the western United States from Canada Mexico making it the most widely distributed pine species in North America (Curtis l Lynch 1965). Although it grows under a variety of environmental conditions and ferent forest types, ponderosa pine is most commonly associated with sites that characterized by low soil moisture and high surface temperature at some time during growing season (Pearson 1951, Foiles and Curtis 1973). Because of its drought sistance ponderosa pine can survive in areas that are too dry for other conifer cies (Foiles and Curtis 1973). Only on the driest sites does ponderosa pine be- e the climax species.

Observations indicate that virgin ponderosa pine stands were uneven-aged stands mposed of even-aged groups (Cooper 1960, Weaver 1943). The age class structure of e stand was maintained by a series of continually occurring natural events. A few es or groups of trees would be killed or die from insect attack, disease, or old age. res, which are known to have been frequent in virgin pine (Weaver 1959), would consume e remains of these trees, often leaving an opening and good seedbed for young ponder- a pine seedlings. Because of the optimum conditions, a large number of seedlings uld likely become established on this seedbed if a seed source was available. Subse- ent fires would remove the smaller trees from the dense areas of reproduction until e most vigorous and rapidly growing saplings were no longer susceptible. The result s a group of even-aged trees that continued their growth until the cycle was repeated eaver 1943). Seedlings occasionally became established beneath the larger mature and ermature trees, but they seldom survived the fires that burned the deep layers of tter and debris. The elimination of reproduction within the pine stand left an open rest floor, usually covered with nutritious vegetation and providing a park-like pearance to the forest as described by early travelers (Cooper 1960, Biswell 1973).

Seedlings that grew beneath mature trees were very susceptible to fire because of unted growth and poor vigor. Cooper (1960) reported that even seedlings that grew thin an open canopy of mature ponderosa pine grew very slowly and were stunted and healthy. The poor growth was attributed to competition for soil moisture rather an light. The effect of light should not be overlooked, however, because light ading of pine seedlings will reduce growth compared to those in full sunlight, and avy shade can cause death (Pearson 1936, 1940). McDonald (1976) discovered that edling height growth was significantly reduced by the presence of mature seed trees feet or closer, and the greater the seed tree density the poorer the height growth. so, removal of the seed trees did not immediately eliminate the inhibitory effect. isture depletion by the seed trees was considered the major limiting factor, but it d not explain continued inhibition after the seed trees were removed. Possible ex- anations were nutrient depletion and toxic substances produced by decaying seed-tree ots.

The following report describes the results from five experiments (a test for vola- le inhibitors, a test for water soluble toxins, the toxicity of plant leachates on ils, a field soil bioasssay, and the effect of seedbeds on germination) that were nducted to determine if phytotoxins are released from mature ponderosa pine trees or e decomposition of its litter, and if these phytotoxins drastically reduced the rmination or growth of ponderosa pine seeds and seedlings.

LITERATURE REVIEW

In recent years, natural plant chemicals have been shown to influence the ecological relationships of plant-plant, plant-animal, and plant-insect interactions (Sondheimer and Simeone 1970, Rice 1974). Plant-plant chemical interaction, or allelopathy, is defined by Rice (1974) as "any direct or indirect harmful effect by one pl (including micro-organisms) on another through the production of chemical compounds that escape into the environment." This definition provides for three factors that must be present in order for allelopathy to be functioning in a plant community: (1) a plant must produce chemicals, (2) these chemicals must get out of the plant an into the environment, and (3) once in the environment, they must have a harmful effe on the plants in the area either directly or indirectly. If any one of these three requirements is absent, then allelopathy is not functioning. It is also important t emphasize that allelopathy is independent of competition. Allelopathy involves the placement of natural chemicals into the environment, whereas competition involves the rivalry for environmental factors such as light, water, nutrients, etc. (Rice 19

The mechanisms for releasing phytotoxins into the environment are quite variabl and dependent upon environmental characteristics. The mechanisms include the leachi of the aerial portions of the plant by rain or fog drip, exudation from the roots, residue left or produced during the decay of plant material, and volatilization (Whittaker 1970, Rice 1974).

Whittaker (1970) considers allelopathy, or the use of a chemical defense by pla as a universal phenomenon; however, he states that the actual significance of allelo pathy is difficult to judge for three reasons. First, the influence of chemistry on community is not always conspicuous to the observer of community relationships; seco there are different degrees of chemical interaction; and third, species may have an evolved tolerance to the chemical defense of others.

Allelopathy or chemical defense in plants is usually thought of as a mechanism by which one species is reduced or eliminated by another species in a community. Oc sionally, the chemicals released are not species specific and they are toxic to the producer species as well. An excellent example occurs in the old-field succession i central Oklahoma and southeast Kansas.

Old-field succession in Oklahoma is characterized by a 2- to 3-year pioneer weed stage, 9- to 13-year annual grass stage, a perennial bunch grass stage of 13 to 30+ years, and finally true prairie, which has never been reached in old-field succesio The initial pioneer weed stage is short because these plants have been shown to elim nate themselves through the production of phytotoxins. These compounds have little effect on the species of the annual grass stage, which then became abundant (Rice 19 A similar phenomenon has been observed in the replant problem of fruit trees includi cherries, grapes, apples, peaches, apricots and plums. When seedlings of these spec are replanted in orchards of the same species, they frequently exhibit retarded shoo and root growth or occasionally even die. Young trees that produce fruit provide lo yields than trees of comparable age planted in nonorchard sites. Detailed studies w peaches and apples indicate that compounds produced by the trees, particularly in th roots, are broken down or rearranged by micro-organisms to toxic compounds that reta seedling growth (Rice 1974).

Allelopathic interactions have been well documented in a variety of deciduous tree pecies. *Eucalyptus globulus* Labill. and *E. camaldulensis* Dehn. influence herbaceous egetation through chemicals that escape into the environment (del Moral and Muller 969, 1970). Sycamore, *Platanus Occidentalis* L. (Al-Naib and Rice 1971), and hackberry, *eltis laevigata* Willd. (Lodhi and Rice 1971, Lodhi 1975) are characterized by sparse egetation beneath their canopies. Experiments with decaying leaves, leaf leachates, nd soils collected beneath the trees lead to the conclusion that phytotoxins were significant factor. Several oak species including *Quercus stellata* Wang., *Q. arilandica* Muench. (McPherson and Thompson 1972) and *Q. falcata* var. *pagodaefolia* 1. (DeBell 1971) produce compounds that inhibit the growth in understory plants.

Another tree species, *Grevillea robusta* Cunn., in the subtropical rain forest of ustralia cannot regenerate in pure stands (Webb and others 1967). Experiments were onducted to show that a water-transferable factor in the rhizosphere from the older rees was responsible for this phenomenon. The commercial production of these trees ay not be possible in pure stands, and a polyculture will be required unless special are and treatment is used to remove toxins from the soil.

Since ponderosa pine is climax only on the driest of sites, the production of an utotoxic chemical could provide survival value to the species. When moisture is imiting, adequate growth and vigor can only be maintained at lower tree densities. herefore, to insure lower densities, chemicals from the mature trees could, perhaps, educe the germination and growth of seedlings, which could then be eliminated by rought or frequent fires. This would prevent overcrowding, stagnation, and competition etween members of the same species. Hall (1976) stated that he suspected "... a elective inhibitory substance in ponderosa pine litter that is destroyed with periodic nderburning. Without fire, this substance is free to build up in the soil and reduce ine growth." If this is the case then fire played a dual role in the ecology of onderosa pine, it eliminated unhealthy seedlings from within mature pine stands, and t prepared seedbeds for pine seeds in open areas by destroying phytotoxins, releasing utrients and reducing competition from other species.

There is some experimental evidence that suggests ponderosa pine produces phytoxins. Jameson (1961) reported that water extracts of ponderosa pine needles inibited wheat radicle growth by 86 percent. Needle extracts also inhibited the adicle growth of two native grass species, *Sitanion hystrix* (Nutt.) J. G. Smith and *puteloua gracilis* (H.B.K.) Lag., and *Pinus ponderosa* (Jameson 1968). Del Moral and ates (1971) observed inhibition of barley by ponderosa pine volatiles and litter water xtracts, although field analysis suggested only weak allelopathic influence with ssociated native species. Eckert (1975) has revealed results which indicate that onderosa pine needles produce chemicals that adversely affect some associated understory species, creating obvious ecotones near ponderosa pine trees.

EXPERIMENTAL STUDIES AND RESULTS

Seed Source and Preparation

The seeds used for experiments during the summer of 1974 were obtained from the U.S. Department of Agriculture Forest Service Nursery at Coeur d'Alene, Idaho. These seeds had been collected from the Seeley Lake Ranger District at an elevation of 4,000 feet ± 500 feet.

During the fall of 1974, approximately 1,000 pine cones were clipped from large ponderosa pine trees on the Blackfoot-Clearwater Game Range, which is adjacent to the Seeley Lake Ranger District, and the location of our field study site where field germination and growth experiments were conducted. The field results will be reported in a separate paper. Approximately 10 pounds of clean seeds were collected. All experiments conducted from the fall of 1974 through 1975 used the seeds from this source.

The seeds in all experiments were soaked in warm water for 24 hours and then plac in 3 percent Chlorox solution for 15 minutes to kill seedcoat pathogens. After soakir in Chlorox, the seeds were stratified at 1° to 5°C for a minimum of 2 weeks. Just prior to use, the stratified seeds were again soaked for 15 minutes in the 3 percent Chlorox solution.

Tests for Volatile Inhibitors

Materials and Methods

To test for the presence of volatile toxins in pine tissues, green needles, surface litter (dried pine needles), decomposing duff (decaying pine needles), roots (1 to 4 cm in diameter), and bark, were collected at the field study site, placed in plastic bags and returned to the laboratory.

The technique used to test for toxic volatile compounds was similar to that described by Muller, and others (1964). Sterilized cellulose sponges were brought to maximum water holding capacity by soaking them in distilled water and allowing them to drain. The wet sponges were placed in sterile 100 x 80 mm petri dishes, and each sponge was covered with 7.0 cm filter paper soaked with distilled water. Fifteen pine seeds were then placed on top of the filter paper.

Two grams of each fresh plant material, described above, were broken up by hand and placed into separate 5 x 2 cm plastic vials. One plastic vial containing plant material (treatment) or no plant material (control) was placed into each petri dish adjacent to the sponge seedbed, permitting only gaseous contact between plant material and seeds. The petri dish was covered and placed randomly into a dark conditioning chamber set at 25°C ± 1°. Five replications were set up for each of the five plant materials and the control.

Germination was recorded daily during which time the seeds were exposed to approximately 1 hour of light. After germination was completed, the radicle lengths were measured from root tip to seed coat or from root tip to the start of the stem in

Table 1.--*Effect of volatile compounds from five ponderosa pine plant materials on the germination and radicle growth of ponderosa pine seedlings.*

Treatment	Germination		Growth rate	
	Experiment A	Experiment B	Experiment A	Experiment B
	Percent		*cm/day*	
Control	[1]40.0a	57.3a	0.74a	0.86a
Root	40.0a	70.0a	.77a	.85a
Litter	33.3a	52.0a	.84a	.93a
Green needle	32.0a	65.3a	.80a	.85a
Duff	29.3a	40.0a	.95a	.90a
Bark	28.0a	61.3a	.79a	.84a

[1]All numbers followed by different letters are significantly different at the 5 percent level or greater.
Growth rate was obtained by dividing average seedling length per replication by average seedling age per replication.

larger seedlings. Since seedling age certainly influences seedling size, growth rates were computed to eliminate the effect of age differences and allow concentration on treatment differences.

The entire experiment was repeated using fresh plant material collected on the same date but stored in plastic bags in a cold room. The two experiments were identical except for the length of the germination periods. In the first experiment A, the germination period was 14 days and in the second experiment B, only 10 days. The germination period was longer in experiment A because of slow germination rates.

For statistical analysis, one-way analysis of variance tests were used. Following these, the Newman-Keuls test for multiple comparisons was utilized to compare treatment means (Hamilton 1965). The homogeneity of the variances was analyzed in all experiments prior to the analysis of variance.

Results

The results of experiments A and B are provided in table 1. It is apparent that there were no volatile compounds in the green needles, roots, bark, surface litter, and decomposing duff of ponderosa pine that inhibited the germination or radicle growth of pine seedlings.

Tests for Water Soluble Toxins

Materials and Methods

One month prior to the start of this experiment, buckets lined with plastic bags and covered with a double layer of cheesecloth secured by rubber bands were placed in openings and beneath the crowns of large ponderosa pine trees at the same range. The "pure" rain water was collected in the openings while that collected beneath the crown canopy was considered at natural crown leachate or throughfall and a potential source of phytotoxins. In addition, the rain water that ran down the bark (stemflow) was

collected by placing metal troughs around the base of several trees. The rain wate throughfall, and stemflow collected was stored in plastic containers in a cold room at 3° to 4°C until used.

Several days prior to the start of this experiment, fresh plant material inclu green needles, litter, decomposing duff, bark, and roots were collected. These sam were returned to the laboratory, placed in an oven set at 40°C, and allowed to dry 48 hours. All the dried samples except the roots were run through a grinder. The roots were cut into small pieces by hand. The grinder was adjusted so that it woul break and crush the dried plant material into smaller pieces but not reduce it to a powder. Each sample was then extracted by placing 225 grams of plant material into 2,025 ml of distilled water to give a 10 percent solution (w/v). The solutions were placed on a shaker for 30 minutes and left overnight, 16 to 20 hours. The plant mat rial was then removed by filtering through paper. Five percent solutions were made for each sample by diluting (1:1) with distilled water. In addition, two of Hoaglan solutions were prepared, a standard Hoagland's (1x) and 5x concentrated Hoagland's, to check potential osmotic effects on germination. A total of 16 different test sol tions was analyzed in this experiment: 10 plant extracts, 3 field rain samples (thro fall, stemflow, rain water), 2 concentrations of Hoagland's solution, and 1 distille water control.

The pH was measured for all the test solutions, and the osmotic potential was determined with a Fiske Osmometer for the 10 percent plant extracts, both Hoagland's solutions, and all the rain samples from the field.

Sterilized cellulose sponges were soaked to water holding capacity in each of t test solutions, and excess solution was allowed to drain off. Each moist sponge was placed into the bottom of a 9.0 cm plastic sterile petri dish and covered with a 7.0 piece of filter paper soaked in the corresponding solution. Fifteen stratified and sterilized ponderosa pine seeds were placed on the filter paper. Each petri dish wa covered and placed randomly into a dark conditioning chamber set at 25°C ± 1°. Ten replications were set up for each treatment.

This entire experiment was conducted twice, the first time (experiment A) was i the summer of 1974 and the second time (experiment B) in the summer of 1975. The germination time for experiment A was 9 days and in experiment B, 11 days. During t summer of 1974, the stemflow was collected from two different rainstorms. The first storm was a drizzling rain, and the second was a very short cloudburst. The drizzli rain produced a light brown stemflow, and the cloudburst produced a very dark brown solution. Because of the color differences, these two samples were kept separate an each tested independently. The stem flow for 1975 was a combination of samples from several storms.

In order to better understand the effect that pH might have on germination, a small germination experiment was conducted using three pH solutions, 3.0, 5.0, and 7 Twenty-five stratified ponderosa pine seeds were placed on top of a filter paper and sponge previously soaked in the test solutions. Six replicates were made for each solution, and all dishes were randomly placed into a conditioning chamber. The germination was checked daily for 9 days. A one-way analysis of variance followed by t Newman-Keuls test was used for statistical analysis.

Results and Discussion

A variety of comparisons can be made between the different solutions tested in this experiment, but the most meaningful for evaluating the presence of a phytotoxin are the comparisons between the plant extracts and the distilled water and "pure" rain controls. In addition, the effect of osmotic potential and pH of the test solutions (table 2) should also be evaluated to ensure that they have not produced the experimental responses observed.

Table 2.--*The pH and osmotic potential of test solutions obtained by artificial extraction and natural leaching of ponderosa pine plant materials*

Solution	Experiment A pH	Experiment A Osmotic Potential (Atms.)	Experiment B Solution	Experiment B pH
Stemflow-2	2.9	-0.3	Bark 10%	3.5
Stemflow-1	3.2	-0.2	Stemflow	3.6
Bark 10%	3.2	-0.4	Green Needle 10%	3.8
Bark 5%	3.5	[1] --	Green Needle 5%	3.9
Green Needle 5%	4.0	--	Bark 5%	3.9
Green Needle 10%	4.0	-2.3	Litter 10%	4.1
Litter 5%	4.0	--	Duff 10%	4.3
Litter 10%	4.1	--	Duff 5%	4.4
Roots 5%	4.1	--	Litter 5%	4.4
Throughfall	4.4	< -0.2	Throughfall	4.7
Roots 10%	4.5	-0.7	Roots 10%	4.9
5x Hoagland	4.5	-3.2	Roots 5%	5.0
Hoagland	4.8	-0.7	Rain	5.9
Duff 10%	5.4	--	Control-Distilled H_2O	7.1
Duff 5%	5.9	--	5x Hoagland	7.1
Rain	6.1	<-0.2	Hoagland	7.3
Control-Distilled H_2O	6.9	<-0.2		

[1] The osmotic potentials were not measured for the 5 percent solutions. Accurate osmotic potentials could not be obtained for the litter and duff 10 percent solutions because of suspended particulates.

In experiment A, green needle 5 percent was the only test solution with a significantly lower germination than the distilled water control (table 3). The germination of pine seeds in rainwater was not significantly different from any of the plant extracts. In experiment B, the germination of the control was significantly greater than green needle 10 percent, whereas the rain was greater than duff 5 and 10 percent, roots 5 and 10 percent, green needle 5 and 10 percent, bark 10 percent, and stemflow.

In both experiments A and B, there was a tendency for those solutions with a low pH to also have a low germination, whereas those solutions with a high pH had a high germination. In a side experiment testing the effects of solution pH only, germination was unaffected by pH values, 3.0, 5.0, and 7.0. Seed germination values varied insignificantly from a low of 80.7 percent in the pH 3.0 solution to a high of 84.0 percent in the pH 7.0 solution. However, the pH of the solutions in experiments A and B could have changed the toxicity of the solutions if the toxic compounds were sensitive to acid or base.

It has been well documented that ponderosa pine seeds exhibit the greatest germination when under some water stress. Germination is usually the highest in solutions with an osmotic potential near -3 atmospheres (Larson and Schubert 1969, Djavanshir and Reid 1975, Rietveld 1975). The lowest osmotic potential recorded in experiments A and B was -3.2 atmospheres for the 5x Hoagland's solutions (table 2); consequently, osmotic potential was not responsible for poor germination in these experiments.

Table 3.--*The effects of water soluble compounds from ponderosa pine plant materials on germination of ponderosa pine seeds (percent)*

Experiment	Germination treatment															
A	H	D-5	C	D-10	TF	5xH	L-5	Rain	L-10	R-10	SF-2	B-10	SF-1	B-5	GN-10	GN-5
	42.0	39.5	32.7	30.0	29.3	28.7	26.0	25.3	24.7	24.0	22.0	21.3	20.0	20.0	19.3	19.3	15.3
B	Rain	H	5xH	L-10	B-5	TF	C	L-5	B-10	D-5	SF	GN-5	R-5	D-10	R-10	GN-10	
	79.3	74.0	68.0	66.7	66.7	66.7	64.7	64.0	62.7	62.0	54.0	52.7	51.3	50.7	19.3	38.7	

Abbreviations: H = 1x Hoaglands; 5xH = 5x Hoaglands; D = Duff, 5 or 10 represents 5 or 10 percent concentration; C = Distilled water control; TF = Throughfall; L = Litter; Rain = Natural rain water; R = Root; SF = Stemflow, 1 and 2 represents collections from two different rainstorms; B = Bark; GN = Green needle.
Numbers not underscored by the same line are significantly different at the 5 percent level.

Table 4.--*The effects of water soluble compounds from ponderosa pine plant materials on the radial growth of ponderosa pine seedlings (cm/day)*

Experiment	Growth treatment															
A	L-5	TF	SF-1	B-5	Rain	B-10	H	C	D-5	SF-2	D-10	L-10	R-5	R-10	GN-5	5xH	GN-10
	1.00	0.99	0.94	0.92	0.92	0.91	0.86	0.85	0.85	0.81	0.81	0.73	0.70	0.66	0.45	0.45	0.44
B	B-10	B-5	H	SF	L-5	C	Rain	L-10	D-5	TF	5xH	D-10	R-10	R-5	GN-5	GN-10	
	0.70	0.70	0.68	0.66	0.65	0.65	0.64	0.62	0.62	0.62	0.61	0.52	0.50	0.50	0.28	0.15	

Abbreviations: same as Table 3.

Examining growth rates for experiment A, table 1 shows that both the distilled water control and the rain were significantly greater than the green needle 5 and 10 percent, and the 5x Hoagland's solution. In addition, the rain was greater than the roots 5 and 10 percent. In experiment B, both the distilled water and the rain were significantly greater than roots 5 and 10 percent, duff 10 percent, and green needle 5 and 10 percent.

The pH of the test solutions had very little influence on the radicle growth of pine seedlings. However, the radicle growth rates of seedlings in solutions with low osmotic potential were significantly lower than for seedlings in solutions of high osmotic potential, suggesting that osmotic potential was important. The growth of ponderosa pine radicles is very sensitive to osmotic potential and generally decreases quite rapidly as the osmotic potential decreases (Larson and Schubert 1969, Djavanshir and Reid 1975, Rietveld 1975). Therefore, some of the reduction in radicle growth associated with 5x Hoagland's (-3.2 atms) and green needle 10 percent (-2.3 atms) can be attributed to their low osmotic potentials.

The green needle extacts both 5 and 10 percent might have contained a phytotoxin, because they significantly reduced germination and radicle growth rates. However, the significance of the green needle results was reduced by the occurrence of fungal and bacterial growth in both experiments A and B. It was the only solution tested that became significantly contaminated. Daily visual observations suggested that the bacteria and fungi did not become important until the later half of each experiment and probably had less influence on germination than on radicle growth. From these visual observations, it was clear that the green needle extracts did reduce radicle growth of the pine seedlings, but the final results were a combination of extract and fungal effects. In addition, the osmotic potential of the green needle extracts was low enough to be a contributing factor to the reduced radicle growth, but not low enough to have reduced germination. It can be concluded that the germination results for the green needle extracts are reliable, but the results for the radicle growth are questionable. If the green needles of ponderosa pine do contain a phytotoxin, then the toxin could be washed from the needles during a rain storm. Therefore, the activity of throughfall could help in evaluating the presence of a green needle toxin. There was no significant difference in germination or growth between throughfall and pure rain treatments in either experiment A or B. This, however, does not eliminate the presence of a very weak toxin in the throughfall that accumulates with time on the forest floor.

There are three other plant extracts, roots, duff, and bark that could also contain a phytotoxin. Both the 5 and 10 percent solutions of roots significantly reduced radicle growth compared to the rain in experiments A and B and to the distilled water control in experiment B. The root extracts had less effect on germination, with a significantly lower germination than rain in experiment B. This suggests the presence of a growth inhibitor within the roots of ponderosa pine. The severity of inhibition is certainly not great as seen in table 3. In the field, pine seedlings germinate on or near the soil surface well above the roots of pine trees; it is very unlikely that this weak toxin would influence seed germination and initial root growth; however, it might influence the later root development.

The germination of seeds in duff 5 and 10 percent solution was significantly lower than rain only in experiment B. Duff 10 percent also reduced radicle growth rates significantly below the control and rain in experiment B; there was no significant difference in experiment A. If there is a toxin present in duff extracts, it is very weak because only the 10 percent solution demonstrated much activity.

The bark 10 percent and its natural counterpart, stemflow, reduced germination compared to rain in experiment B. Neither solution interfered with the radicle growth.

To summarize, the results of this experiment indicated that the water extract of green needles, roots, duff, and bark of ponderosa pine might contain growth inhibitors. Closer observation, however, indicates that the inhibition of radicle growth by the green needle extracts may have been the combined effects of inhibitor, osmotic potential, and fungal activity. The reduced germination caused by the green needles was most likely the work of the inhibitor alone. Throughfall, which is a natural leachate of pine needles, had no effect on the germination or radicle growth of the pine seeds. Therefore these results do not support the presence of a strong inhibitor, but they do not completely eliminate the presence of a weak toxin that may occur in low concentrations in the leachate and accumulates on or in the soil. The water extract of roots reduced germination only slightly, but consistently reduced radicle growth rates. Although the root extracts were inhibitory, they did not severely damage the growing ability of the pine radicles. The duff extracts were marginally toxic because the 5 and 10 percent solutions were inhibitory to germination in experiment B; also the 10 percent solution reduced radicle growth in experiment B. Germination reduction by bark and stemflow was minimal.

It can be concluded from this experiment that the green needles and roots of ponderosa pine are the most likely tissues containing phytotoxins that interfere with the germination and growth of ponderosa pine seedlings. Bark and duff may contain a weak toxin, but it is probably not significant unless it accumulates in the soil.

Toxicity of Plant Leachates on Soils

Materials and Methods

This experiment was conducted twice, experiment A in the summer of 1974 and experiment B in the summer of 1975. There were some technical differences in the setup of each, so the two experimental designs will be discussed separately.

In experiment A, large samples of green needles, bark, litter, and decomposing duff were collected at the field site and returned to the laboratory. Each plant material was separately placed on a plastic-lined trough and sprayed with a fine mist of distilled water on a ratio of 1 part plant material to 4 parts of water. The leachate was collected and filtered through paper, approximately one-third was stored in a cold room at 1° to 4°C, and the remaining two-thirds was frozen until needed.

Soil was collected in large openings away from pine tree influence at the game range. These soils were passed through a 2.0 mm sieve, mixed thoroughly, and then placed into 4-inch plastic pots. Ten replicates were set up for each leachate and a distilled water control. Fifteen stratified and sterilized ponderosa pine seeds were added to each pot. The ten treatment replicates were each watered with 75 ml of their corresponding leachate or distilled water in the case of the control. The treatments were then randomly placed in the greenhouse. The pots were watered when needed with 25 ml of the corresponding solution. Germination was checked every day for 15 days, then all seedlings were allowed to grow an additional 10 days at which time all but the largest three seedlings were removed. The remaining three seedlings were allowed an additional 1 month growing period at which time the seedlings were harvested, ovendried at 70°C for 48 hours, and weighed.

In experiment B the same four plant materials were collected and prepared as in experiment A. In addition to the distilled water control, a Hoagland's solution was included in the list of test solutions. This treatment was added as a nutrient-enriched control for comparison with pine leachates that might have contained higher quantities of nutrients than the distilled water.

It had been observed in experiment A that the roots of the 2-month-old seedlings were coiled around the bottom of the 4-inch pots. In order to eliminate physical

barriers for root growth in experiment B, the sieved soil was placed in root boxes in the greenhouse. Thirty stratified and sterilized ponderosa pine seeds were planted in each box. Three replicates were set up for each of the four leachates, the Hoagland's solution, and the distilled water control. Each root box was initially watered with 200 ml of the appropriate test solution followed by 100 ml every other day.

The seedlings were allowed to germinate and grow for 35 days, then all but the largest 10 seedlings were removed from each root box. Germination was checked daily until the thinning. The remaining 10 seedlings were allowed to grow an additional 29 days at which time the soil was washed away from the roots and the seedlings collected. The root lengths, stem lengths, number of laterals over 1.0 cm, and biomass of the roots and crowns were measured for each treatment.

The one-way analysis of variance and Newman-Keuls tests were performed for statistical analysis.

Results and Discussion

In both experiments A and B, there was no significant difference in germination between any of the plant leachates and the distilled water control (table 5). However, the seeds watered with the Hoagland's solution in experiment B had a significantly lower germination than the seeds watered with the four plant solutions and the control. These data show that under these conditions, none of the leachates contained phytotoxins that inhibited the germination of pine seeds. The reason for low germination in the Hoagland's treatment is uncertain.

In experiment A there was no significant difference in total seedling weight and shoot weight between the treatments. There was, however, a significant difference in root weights for duff and bark compared to the control. The reduced root weights of the duff treatment resulted in a shoot/root ratio that was significantly larger than all other treatments and the control.

In experiment B there was no significant difference in total seedling weight, root and shoot weight, or shoot/root ratios between the plant leachate treatments and the distilled water control. The Hoagland's solution was significantly lower in root weight than the other solutions, which again resulted in a very large shoot/root ratio.

In experiment B the entire seedlings were extracted from the root boxes, the roots and crown lengths were measured, and the number of lateral roots greater than 1.0 cm were counted. The taproots of seedlings grown in the Hoagland's solution were equal in length with the taproots from seedlings grown in the other solutions (table 5), but the Hoagland's seedlings had a reduced number of lateral roots. A reduction in the number of laterals resulted in reduced root weights for the Hoagland's treatment but is probably not representative of a disadvantaged seedling under these growing conditions. A similar situation could have existed in experiment A reducing the root weights of seedlings watered with duff and bark leachates. Neither bark nor duff leachates reduced root growth in experiment B.

Although this experiment produced no evidence of a germination inhibitor, the experimental design did not eliminate all mechanisms of inhibition associated with leachates. Plant compounds may have to accumulate in the soils over a period of time to reach active concentrations. In this experiment, the soils were not watered with plant leachate until the seeds were sown, and the germination was quite rapid. Therefore, there may not have been sufficient time for the inhibitor to accumulate to the point where it could have affected germination. It is also possible that compounds in the leachates are broken down or rearranged to produce the inhibitor and there may not have been sufficient time for the breakdown product to reach inhibitory concentrations. Therefore, this experiment did not disprove these two mechanisms.

Table 5.--*The effect of artificial leachates from ponderosa pine on seed germination and seedling growth of ponderosa pine in soil.*

Parameter	Artificial leachate											
	Litter		Green needle		Bark		Duff		Control		Hoagland	
	A	B	A	B	A	B	A	B	A	B	A	B
Germination (percent)	[1] 66.0a	76.7a	64.0a	67.9a	63.3a	71.1a	62.0a	68.9a	56.7a	73.3a	--	48.9b
Total seedling weight (g)	0.0863a	0.0891a	0.0850a	0.0755a	0.0805a	0.0890a	0.0806a	0.0771a	0.0925a	0.0852a	--	0.0694a
Shoot weight (g)	0.0490a	0.0486a	0.0457a	0.0425a	0.0473a	0.0493a	0.0511a	0.0430a	0.0499a	0.0464a	--	0.0475a
Root weight (g)	0.0373 a,b,c	0.0405a	0.0393 a,b	0.0330a	0.0332 b,c	0.0397a	0.0295c	0.0341a	0.0426a	0.0388a	--	0.0220b
Shoot/root by weight	1.36b	1.24b	1.19b	1.31b	1.46b	1.24b	1.80a	1.30b	1.18b	1.20b	--	2.16a
Stem length (cm)		6.28a		5.78a		6.61a		5.89a		6.27a		5.74a
Taproot length (cm)		24.8a		24.6a		26.0a		24.7a		27.2a		25.4a
Average no. lateral roots longer than 1.0 cm		18.8a		13.8a		19.6a		15.9a		17.8a		5.5b

[1] Numbers within an experiment followed by different letters are significantly different at the 5 percent level or greater. The results of experiments A and B were not compared statistically.

Seedling growth was not affected by green needle and litter leachates [illegible] an indication that duff and bark leachates may, under certain conditions, slightly reduce root weights, but the results were not reproducible. Seedlings grown in Hoagland's solution also exhibited reduced root weights.

Field Soil Bioassay

Materials and Methods

This experiment was conducted twice, experiment A in the summer of 1974 and experiment B in the summer of 1975. Because of differences in the experimental design, each will be discussed separately.

In experiment A, the upper 5.0 cm of soil was collected from five areas in the open and five areas under pine canopies. Each of the 10 different soils was sifted twice through a 2.0 mm sieve to remove large pieces of organic matter and then placed into 10 greenhouse pots (4-inch size). Fifteen stratified and sterilized ponderosa pine seeds were planted into each pot, and the pots were randomly placed in the greenhouse. All soils were given equal volumes of tap water at periodic intervals as needed. The germination was recorded for 15 days, and then all but the largest three seedlings were removed from each pot. The remaining three seedlings were harvested after an additional 16-day growing period. The biomass of both roots and shoots was measured after ovendrying at 70°C for 48 hours.

Experiment B was very similar to A in that soils were collected from five open areas and from five areas under pine canopies. However, in experiment B, the upper 15 cm of the soil was lifted from the ground with minimal disturbance and placed directly into 6-inch green house pots. Three replications were taken from each of the 10 different collection sites. Each pot was saturated with tap water and planted with 30 stratified and sterilized ponderosa pine seeds and randomly placed in the greenhouse. All pots were given equal volumes of water at intervals as needed. Germination and initial growth was observed for 21 days when all but the largest seven seedlings were removed from each pot. These seedlings were grown an additional 56 days, at which time they were harvested, and the root and shoot weighed after drying 70°C for 48 hours.

A series of subsamples from the two soil groups were taken for nutrient analysis. The concentration of eight cations was measured by atomic absorption. The various treatment subsamples could not be paired statistically, so a nested experiment analysis of variance was used and followed by the Newman-Keuls test.

Results and Discussion

Although the experimental design was different between A and B, the results were essentially the same. In both A and B, the germination of pine seeds in soils collected from the openings was significantly greater than the germination of pine seeds in soils collected beneath a pine canopy (table 6). Although germination of the canopy treatment was significantly lower than the opening treatment, it was certainly not a drastic difference. Since both treatments received equal amounts of water and sunlight and were, therefore, influenced by similar temperatures, soil factors, would have to account for germination differences.

It was observed that the canopy soil contained larger amounts of organic matter than the opening soils, even in experiment A where the soils were sieved twice. Soil surfaces in which the seeds were planted, dried quite rapidly after watering. It is possible that the higher amounts of organic matter in the canopy soils created greater moisture tensions that reduced germination.

Table 6.--*The effect of soil collected in the opening and beneath a ponderosa pine canopy on the germination and growth of pondersoa pine seedlings*

Parameter	Germination and Growth Experiments					
	1	2	3	4	5	Mean[1]
Germination (Percent)			EXPERIMENT A			
Opening Sites	76.0	64.0	66.7	70.7	65.3	68.5a
Canopy Sites	66.0	55.3	58.0	60.0	58.7	59.7b
			EXPERIMENT B			
Opening Sites	83.8	64.4	81.1	63.3	73.3	73.1c
Canopy Sites	40.0	57.8	55.6	53.3	74.4	56.2d
Total Seedling weight (g)			EXPERIMENT A			
Opening Sites	0.1486	0.1190	0.1105	0.1408	0.1439	0.1326a
Canopy Sites	0.1282	0.1353	0.1217	0.1265	0.1215	0.1264a
			EXPERIMENT B			
Opening Sites	0.1253	0.0883	0.1076	0.1202	0.1177	0.1111b
Canopy Sites	0.1414	0.1532	0.1010	0.0749	0.1578	0.1257b
Shoot weight (g)			EXPERIMENT A			
Opening Sites	0.1077	0.0906	0.0851	0.1037	0.1069	0.0988a
Canopy Sites	0.0949	0.0975	0.0912	0.0965	0.0923	0.0945a
			EXPERIMENT B			
Opening Sites	0.0708	0.0488	0.0603	0.0647	0.0689	0.0626b
Canopy Sites	0.0807	0.0835	0.0554	0.0424	0.0857	0.0695b
Root weight (g)			EXPERIMENT A			
Opening Sites	0.0419	0.0283	0.0255	0.0371	0.0370	0.0339a
Canopy Sites	0.0333	0.0378	0.0294	0.0310	0.0292	0.0321a
			EXPERIMENT B			
Opening Sites	0.0545	0.0395	0.0473	0.0555	0.0488	0.0487b
Canopy Sites	0.0608	0.0698	0.0456	0.0325	0.0720	0.0561b

[1]Means in the same experiment followed by different letters are significantly different at the 5 percent level.

It is also possible that weak phytotoxins could have been responsible. The extract experiment revealed potential phytotoxins in green needles, bark, duff, and roots, and the soil leachates experiments failed to eliminate the possibility of weak toxins or breakdown products accumulating on the soil. Therefore, weak toxins in the canopy soil could have reduced the germination.

Another explanation is an interaction or the combined effects of moisture tension and a weak phytotoxin working synergistically to reduce germination in the canopy soils. The two factors working simultaneously may be more inhibitory than either factor separately

The factors influencing germination apparently had no effect on the growth and development of young pine seedlings, since there was no significant difference in total seedling weights, shoot weights, or root weights between treatments in either experiment A or B. There were greater concentrations of nutrients measured in the canopy soils, but the differences were apparently not great enough to affect seedling growth.

Seedbed Effect on Germination

Materials and Methods

The possibility that the germination and growth of ponderosa pine seeds and seedlings are influenced by the seedbed in which the seeds overwintered was investigated by a field and a laboratory experiment.

In the field seedbed experiment, seven different seedbeds were prepared at the edge of a small opening at the game range field site on November 20, 1974. Six of the seedbeds were set up in the opening and one under the canopy of several trees bordering the opening. The seedbed beneath the canopy was prepared by scraping away the litter and duff to expose the surface soil. This treatment shall be referred to as the canopy topsoil (canopy). The vegetation and litter were scraped away from six small areas in the opening, and each was covered with one of the following materials: topsoil collected from under a ponderosa pine canopy, referred to as canopy topsoil (opening); topsoil from a large opening; subsoil from a large opening; litter; decomposing duff; and decomposing duff with litter on top. A large number of unstratified ponderosa pine seeds were then placed on each of the seven seedbeds. The seeds on the soil seedbeds were not treated further, while those in plant materials were covered with the corresponding plant material. In the duff and litter combined treatment, the pine seeds were placed on top of decomposing duff, and the litter was then placed over the top of the seeds. Small hardware cloth exclosures were placed over each seedbed to ban rodents.

On May 9, 1975, the seeds were collected and taken to the laboratory where the germination tests were conducted. Sterilized cellulose sponges were soaked in distilled water, drained, and placed in the bottom of 9 cm plastic petri dishes. Each sponge was covered with a wet 7.0 cm piece of filter paper. Twenty seeds from each treatment were placed in respective petri dishes. Four replications were set up for each treatment. The petri dishes were covered and randomly placed in a growth chamber set at 25° to 27°C. The germination was checked daily for 1 week.

For the laboratory experiment, litter, duff, and topsoil from under a ponderosa pine canopy were collected along with topsoil from a nearby opening on November 20, 1974. These materials were returned to the laboratory to be used as overwintering seedbeds for ponderosa pine seeds. The litter and duff samples were soaked separately for two hours in distilled water and then transferred to 100 by 80 mm petri dishes. A third seedbed was set up using a combination of duff covered with litter. The opening and canopy soils were placed into petri dishes and brought to saturation with distilled water. The control was silica (sand) brought to saturation. Eight replications were

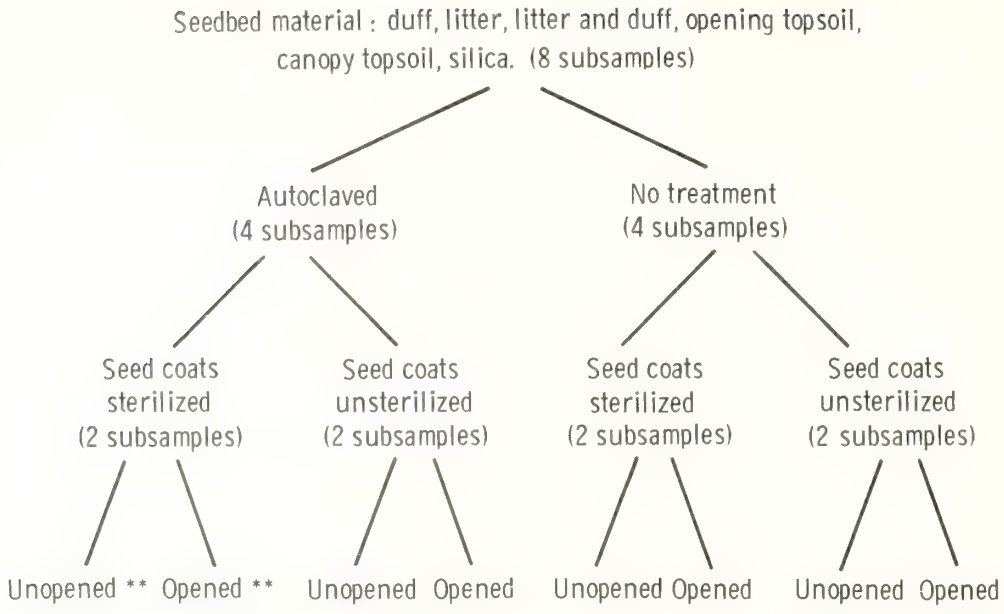
Seedbed material : duff, litter, litter and duff, opening topsoil, canopy topsoil, silica. (8 subsamples)
Autoclaved (4 subsamples)
No treatment (4 subsamples)
Seed coats sterilized (2 subsamples)
Seed coats unsterilized (2 subsamples)
Seed coats sterilized (2 subsamples)
Seed coats unsterilized (2 subsamples)
Unopened ** Opened **
Unopened Opened
Unopened Opened
Unopened Opened

*Figure 1.--Artificial overwintering treatments for laboratory seedbed experiment. *After stratification, subsamples were placed directly into the germination chamber. **After stratification, subsamples were opened, germinants were counted, and the remaining seeds were placed into chamber.*

made for each seedbed material. One half (four) of the replicates for each seedbed were sterilized by autoclaving for 30 minutes. The remaining four replicates were left unsterilized. Two of the autoclaved and two of the unautoclaved replicates received ponderosa pine seeds that had been treated with a powder fungicide. The remaining two autoclaved and unautoclaved replicates received untreated pine seeds. The seeds were allocated by weight rather than by numbers. This design resulted in four degrees of sterilization in each seedbed; i.e., duff autoclaved and seeds coats sterilized, duff autoclaved and seeds coats not sterilized, duff not autoclaved and seeds coats sterilized, and duff not autoclaved and seeds coats not sterilized, with duplicate samples for each (fig. 1). The covered petri dishes were then randomly placed into a dark coldroom at 2° to 3°C for 5 months.

On April 22, 1975, the petri dishes were removed from the coldroom. It was observed that some germination had already taken place within the dishes, so one dish from each duplicated sterilization treatment for each seedbed was opened and the germination percentage determined by counting all the seeds. This, however, was only a partial germination, so in order to determine complete germination, two 15-seed subsamples were taken from the ungerminated seeds. The seeds of each subsample were placed into petri dishes containing a moist sponge covered with filter paper; the petri dishes were covered and placed into a dark growth chamber at 24° to 26°C. The germination was recorded daily for 7 days.

The other half of the artificial overwintering petri dishes were placed directly from the coldroom into the dark growth chamber set at 24° to 26°C. After a 7-day period the dishes were removed and the percentage germination determined by counting all the seeds.

The statistical analysis for the field seedbed experiment included the one-way analysis of variance and the Newman-Keuls test for multiple comparisons. Statistics were not needed in the laboratory seedbed test because of similarity of results.

Results and Discussion

In the field seedbed experiment, germination was fairly high in most treatments, ranging from 62.5 percent to 91.3 percent. Seeds overwintering on the opening topsoil, the canopy topsoil (opening) and the duff seedbeds had significantly better germination than the seeds on the opening subsoil, litter, litter and duff, and canopy topsoil (canopy). The germination of the seeds from the canopy topsoil (canopy) was significantly lower than for seeds on all other seedbeds as shown in the following tabulation:

Seedbed	*Germination*[1]
Opening topsoil	91.3 a
Canopy topsoil (open)	91.3 a
Duff	88.8 a
Litter and duff	80.0 b
Litter	78.8 b
Opening subsoil	77.5 b
Canopy topsoil (canopy)	62.5 c

Periodic observations in late winter and early spring revealed that soils under the pine canopies accumulated less snow than in the openings, and the canopy soils were the first to lose their snow cover in the spring. The viability of the seeds from the canopy could be reduced by exposure to cold and dry conditions after the snow melts, causing lower germination. A phytotoxin could have also been responsible for the reduced germination in the canopy topsoil (canopy) seedbed. If so, the movement of the canopy topsoil to the opening eliminated its effect, possibly due to increased moisture. Also, both moisture stress and phytotoxins may have been acting simultaneously.

The poorest germination of seeds overwintering in the open occurred from beds of litter, litter and duff, and opening subsoil. It is very unlikely that opening subsoil contains phytotoxins; physical soil properties may have been responsible. The germination of seeds from litter, and litter and duff seedbeds was reduced, but it was not a drastic reduction. Phytotoxins may have been responsible, although opening subsoil seeds were not influenced by phytotoxins and their germination was reduced. Thus other environmental factors such as those in the subsoil seedbeds could have reduced germination in the duff, and litter and duff seedbeds as well.

This experiment demonstrates that pine seeds overwintering on a topsoil seedbed in the open, away from the influence of the pine canopy, have the greatest potential for germination at the end of winter.

In the laboratory seedbed experiment, the results of the duplicate samples--one assayed after transferring the petri dish to the growth chamber and the other assayed by first counting the number of seeds that germinated during the experiment and transferring subsamples of the ungerminated population to the growth chamber--were very similar, so they were averaged. In the design of this experiment, fungal growth was not expected to occur in seedbeds that had been autoclaved and the seedcoats treated with fungicide; however, these samples did become contaminated. Seedbeds composed of

[1]Numbers followed by different letters are significantly different at the 5 percent level.

Table 7.--*The germination of ponderosa pine seeds stratified in the laboratory on a variety of seedbeds with different fungal control measures.*

Treatment[1]		Seedbed						
Seedbed	Seed	Duff	Litter	Litter and duff	Opening topsoil	Canopy topsoil	Silica	Average
		Percent						
--	--	80.2	84.3	87.8	88.3	88.4	81.4	85.1 ±9.2[2]
A	--	87.1	88.7	88.7	83.5	87.5	84.8	86.7 ±4.8
--	F	90.2	91.1	87.2	82.5	84.8	90.5	87.7 ±7.8
A	F	87.0	77.4	81.8	82.4	83.2	76.6	81.4 ±8.6
Average		86.1 ±7.3	85.4 ±10.4	86.4 ±5.4	84.2 ±4.8	86.0 ±4.2	83.3 ±10.1	

[1]A = Autoclaved, F = Fungicide
[2] ± Standard Deviation

plant material were more heavily infected than the topsoil seedbeds, and the silica could not support a fungus because of insufficient nutrients. The combined autoclaved-fungicide seedbeds were probably contaminated by fungal spores introduced with the seeds. In general, all seedbeds that were autoclaved had a heavier fungal growth than those that were not. This may have been due to the elimination of competing bacterial and fungal populations, the breakdown of a fungicidal compound in the seedbed during autoclaving, or the release of nutrients by autoclaving.

The seedcoat fungicide was quite effective in eliminating seedcoat contamination when the seedbeds were not autoclaved. The fungicide was probably less effective in the autoclaved seedbeds because of the larger fungus populations in these dishes.

Table 7 shows that within any one seedbed there was essentially no difference in germination between any of the treatment groups. Consequently, the results for the treatments within each seedbed were averaged and compared. When this was done, it became obvious that there was no difference in germination due to the seedbed on which the seeds were stratified.

Similar results were obtained by comparing the germination of seeds from different seedbeds that had received the same treatment. Again, there were no differences, so the results for the six seedbeds were averaged within each treatment and then compared. No differences were observed in germination between treatments.

Unlike the field experiment, no seedbed in the laboratory hindered the germination potential of the ponderosa pine seeds. The absence of fungus on the seedbed (silica seedbed) or the absence of fungus on the seedcoats (seedcoat fungicide treatments) did not improve the germination, or conversely, the presence of fungus did not significantly reduce germination.

In the laboratory seedbed experiments, all of the seedbed materials were very moist, with uniform temperatures. In the field seedbed experiments, the opening seedbed received more rain and snow than the canopy seedbed. The opening seeds all had greater germination, although there was some difference between opening treatments. Together these two experiments suggest that the seedbed on which pine seeds overwinter is not greatly significant providing there is adequate moisture.

ALLELOPATHY AND MYCORRHIZAE

It is well known that most forest tress require mycorrhizal associations for good growth and survival. Although trees can survive without mycorrhizae, under natural conditions they usually become stunted and may die (Meyer 1973). Therefore, chemicals from natural foliage leachates, the decomposition of litter, or chemicals from micro-organisms produced during litter decomposition that inhibit the growth and development of mycorrhizae could indirectly reduce the growth and development of conifer seedlings.

Handley (1963) describes the suppression of tree growth when planted on ancient *Calluna* heathlands in Europe. He attributed the inhibition to antibiotics (phytotoxins) produced by the *Calluna* roots or its associated mycorrhizae that inhibited the growth and development of mycorrhizal associates on the sensitive tree species. Without sufficient mycorrhizae tree growth was checked. Brown and Mikola (1974) conducted experiments that indicated that lichens, particularly *Cladonia alpestris*, produce toxic chemicals that adversely affect the mycorrhizae of pine and spruce seedlings in Finland and consequently reduce their growth.

The effect of pine leachates and extracts were not tested for toxicity to associated ectomycorrhizae in these experiments, but the mycorrhizae were examined on pine seedlings grown under a variety of conditions at the field study site. The field results will be presented in a separate publication.

Future allelopathic studies of tree species with ectomycorrhizal associates should include investigation into both the direct suppression of seedlings by phytotoxins, as well as the indirect suppression of seedlings through the inhibition of mycorrhizae.

SUMMARY

Volatile compounds present in ponderosa pine tissues (green needles, surface litter, decomposing duff, roots, and bark) did not inhibit the germination of pine seeds and the growth of seedling radicles. In the tests for water-soluble inhibitors, the germination of ponderosa pine seeds was inhibited by the 10 percent bark solution, the 5 and 10 percent duff solution, the natural stemflow, the 5 and 10 percent green needle solution, and the 5 and 10 percent root solution compared to the rainwater controls. Throughfall,

a natural leachate of green needles, did not inhibit seed germination. However, the two artificial green needle solutions were probably more concentrated than the throughfall, hence the increased inhibition. The natural stemflow may have been more concentrated than either of the prepared bark solutions because it was slightly inhibitory, whereas the prepared solutions were not.

The radicle growth rates of seedlings exposed to pure rainwater were significantly greater than growth rates in the 5 and 10 percent root solutions, the 5 and 10 percent green needle solutions, the 10 percent duff, and the 10 percent litter solutions. Again both green needle solutions were inhibitory, but throughfall was not. Some of the inhibitory effects of the green needle solution could be attributed to the osmotic potential of the solution and fungal growth. Recognizing that the solutions used in this experiment were highly concentrated, the green needle and root extracts were the two most toxic solutions, and the bark and duff extracts were marginally active.

In the soil leachate experiments, no significant differences in germination were observed between the distilled water control and any of the leachate treatments. In one replication of this experiment, duff and bark leachates reduced root weights compared to controls; however, in the second replication, neither of these solutions were inhibitory. In most cases, both shoot and root weights of seedlings watered with plant leachates were similar to the distilled water controls.

In the field soil bioassay, pine seed germination was significantly lower in the canopy soils than in the opening soils in duplicate experiments. This may have been caused by differences in soil structure due to larger amounts of organic matter in the canopy soils creating water potential differences. It is also possible that a phytotoxin was responsible. Although leachate experiments failed to find strong germination inhibitors in pine tissues, it is possible that weak phytotoxins accumulated on canopy soils or were produced by microbial activity. An interaction between a weak phytotoxin and moisture tensions may have also reduced the germination. Shoot, root, and total seedling weights were very similar regardless of treatment.

Two separate experiments were performed to test the overwintering seedbed effect on germination. In the first experiment, the seeds overwintered in the field on various seedbeds with and without a canopy cover. Seeds away from the canopy influence showed the greatest germination. This may have been caused by increased moisture and the better stratification of seeds under a deep layer of snow in the openings, a weak phytotoxin under the canopy, or both. Seeds stratified on litter, and litter and duff seedbeds had the poorest germination for those seedbeds located away from the canopy influence.

The second seedbed experiment was set up in the laboratory where the seeds were stratified on a variety of seedbed materials in a coldroom. Germination percentages were very similar regardless of the seedbed. Fungal contamination did not reduce seed viability.

CONCLUSIONS

No highly toxic compounds in the live or dead tissues of ponderosa pine, volatile or water soluble, drastically reduced the germination or early growth of ponderosa pine seedlings.

Germination was reduced if the seeds overwintered beneath the canopy of mature pine trees, or if the seeds were germinated in soil collected from beneath the canopy of mature trees. The exact cause of this reduction was not determined although it could be explained by weak phytotoxins, the moisture conditions of the seeds, or a combination of the two. If phytotoxins were responsible, they did not affect the growth of the seedlings that did germinate.

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Live and dead tissues of ponderosa pine were examined for volatile and water-extractable phytotoxins that inhibit the germination and early growth of ponderosa pine seedlings. No highly toxic substances were discovered. Germination of ponderosa pine seeds was reduced if the seeds were sown on soils collected from beneath a pine canopy.

KEYWORDS: Pinus ponderosa Laws., germination, allelopathy, phytotoxins, chemical ecology.

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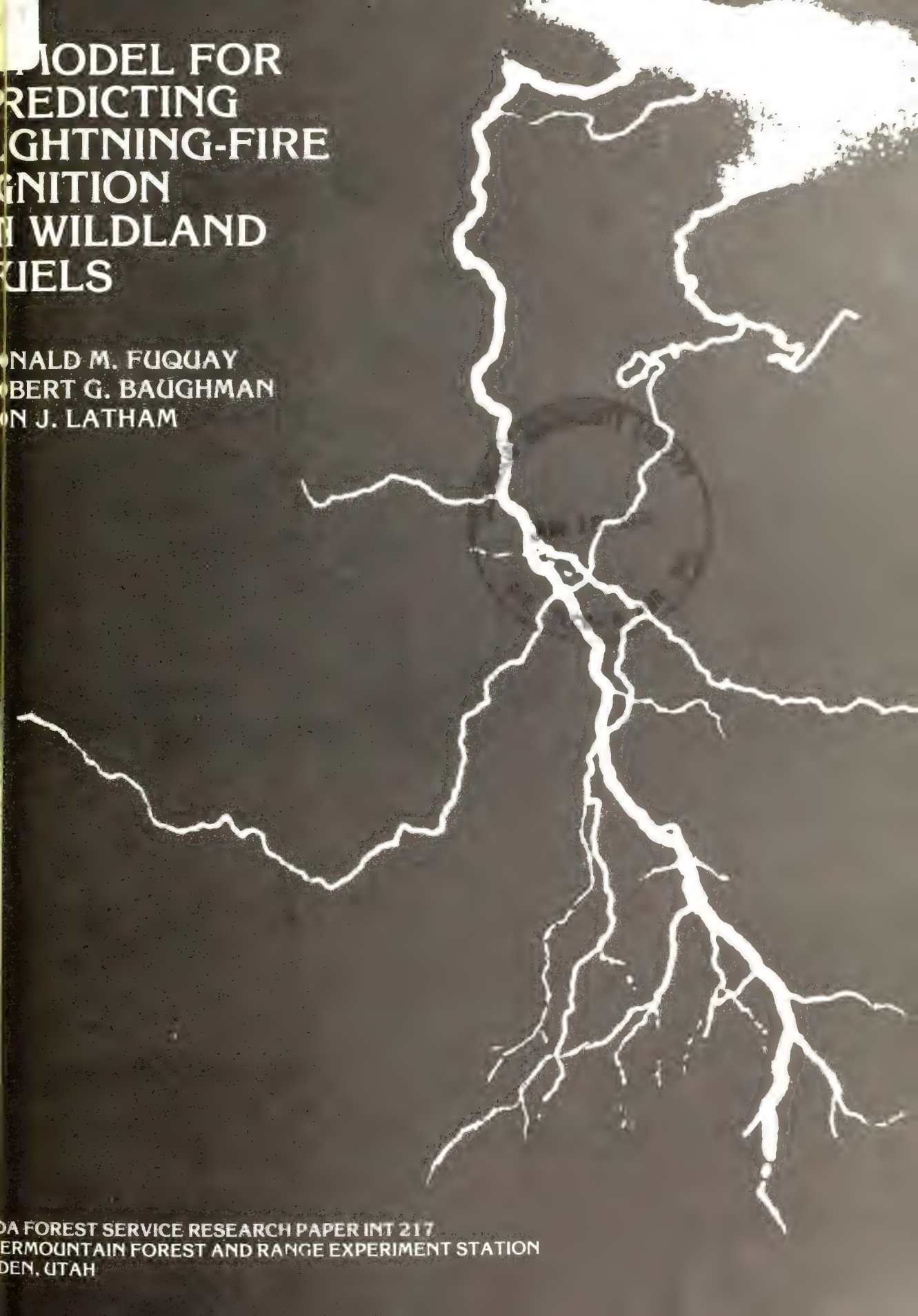
MODEL FOR PREDICTING GHTNING-FIRE GNITION I WILDLAND UELS

NALD M. FUQUAY
BERT G. BAUGHMAN
N J. LATHAM



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A MODEL FOR PREDICTING LIGHTNING FIRE IGNITION IN WILDLAND FUELS

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PREFACE

This report is the second in a planned series describing the concepts, development, and application of lightning-fire models. These reports are:

1. A Conceptual Model for Lightning-Fire Prediction
   (Donald M. Fuquay)

The first report in the series will describe a conceptual model that tells the probability of forest fuel ignition by lightning. Fire ignition potential is described in terms of characteristics of summer storms and individual lightning flashes, fuel bed, and fuel moisture.

2. A Model for Predicting Lightning-Fire Ignition in Wildland Fuels
   (Donald M. Fuquay, Robert G. Baughman, and Don J. Latham)

This report describes a model for predicting the number of lightning-caused ignitions in forest fuels. The model is based on the physical processes involved in ignition of fine woody fuels by lightning and the chance occurrence of the simultaneous events required for fire ignition. Input information includes lightning activity, storm movement, fuel moisture and fuel bulk density.

3. Forecasting Lightning Activity and Associated Weather
   (Donald M. Fuquay)

The third report will present guidelines for forecasting Lightning Activity Levels required for the 1978 version of the National Fire-Danger Rating System (NFDRS). The concepts, organization, and data base for the Lightning Activity Level (LAL) Guide plus a forecast and verification guide will be described.

RESEARCH SUMMARY

A model has been developed for predicting the number of lightning-fire ignitions in wildland fuels. The model is based on both stochastic and physical processes. Stochastic methods are used to generalize the lightning storm characteristics and site conditions that affect the potential for ignition. Physical processes are involved in determining the ignition probability of woody fuels by individual lightning events. Input required to operate the model includes lightning activity, upper air windspeed (storm movement), fuel moisture, and fuel bulk density. The model can be used either to predict ignitions at some future time by using forecast data or to estimate the number of fire ignitions actually occurring by using current data.

A lightning activity level (LAL) guide has been provided as a means for field personnel to interact with the model. Although the predicted LAL and upper air windspeed are provided by the National Weather Service, the LAL guide can be used in the field to determine the actual lightning activity level. The LAL guide is given in terms of an index that describes the cloud and storm development and expected amount of cloud-to-ground (CG) lightning. For example, an LAL index of 1 describes the condition of no thunderstorms, while an LAL of 5 describes a very active thunderstorm development with over three CG discharges per minute. By referring to the LAL guide, field personnel can use cloud descriptions, rate and amount of CG lightning, and area coverage of storms to confirm lightning activity level forecasts.

The lightning-fire ignition model estimates the maximum number of ignitions to be expected under specified conditions. The probability of these ignitions becoming reported fires is not covered in this model development, but is the subject of further work.

CONTENTS

	Page
INTRODUCTION	1
COMPONENTS OF THE LIGHTNING-FIRE IGNITION MODEL	3
Lightning Activity Level	3
Meteorological Considerations	3
Ignition	5
Model Structure	5
HOW THE MODEL WORKS	6
Lightning Activity Level Guide	6
Rainfall Effect on Fuel Moisture	9
Ignition Probability	14
The Model	18
CONCLUSIONS	20
PUBLICATIONS CITED	20

INTRODUCTION

This report, the second of several planned on the topic of lightning-caused fires see Preface), describes the development and structure of a model for predicting the gnition of wildland fuels by lightning. The model is both physical and stochastic in tructure. The physical processes for ignition of fine woody fuels by lightning are he basis for the model. Stochastic processes are used to generalize site conditions or a large area and the chance occurrence of simultaneous events required for ignition.

The updated National Fire-Danger Rating System (1978 version) uses a lightning-ire occurrence index as a measure of lightning-fire risk. We have developed a light-ing ignition model that could provide the basis for a lightning-caused fire occurrence ndex within the context and limitations of the National Fire-Danger Rating System NFDRS). In keeping with the NFDRS, an *occurrence index* is a number on a relative cale, usually 0-100, relating to the potential fire incidence within a protection unit. he *model*, as discussed here, provides a systematic means of producing a lightning-fire ccurrence index.

The ignition of forest fuel by lightning depends on a large number of variables nd chance factors. The development of this lightning-fire ignition model assumes hat the probability of ignitions resulting from lightning discharges can be estimated rom a very limited amount of physical data, particularly on fuel and storm character-stics. The utility of the model will depend, for the most part, on our ability to eneralize those conditions within the wildland environment that most influence the gnition processes.

The following general guidelines were used to develop the lightning-fire ignition odel:

1. The model had to be compatible with the philosophy of the NFDRS; it should valuate the "worst" conditions within a rating area.

2. The model had to provide an estimate of the *maximum* expected number of igni-ions, using either forecasted or observed values of the critical variables.

3. Guidelines were needed for forecasting the essential variables and for veri-ying that the forecast events occurred.

"A Conceptual Model for Lightning-Fire Prediction" (Fuquay 1974[1]), summarized o first attempt to develop a lightning-fire prediction model. This earlier model generates a probability of forest fuel ignition by lightning. Fire ignition potential described in terms of characteristics of summer storms and individual lightning flas fuel bed descriptors, and fuel moisture. The ignition generator in the earlier mode corresponding to the Lightning Risk (LR) factor in the present NFDRS, is based on hi torical probabilities of storm occurrence and flash characteristics, and on lightnin forecasts. Prediction, or estimate, of reported fires depends on the area distribut of specified fuels, state of the fuel, ambient meteorological factors, and a probabi of sustained ignition based on fire spread models. Some features of this earlier mo were used in developing the model described here.

The lightning-fire ignition model estimates the maximum number of *ignitions* to expected under specified conditions. The probability of these ignitions becoming *reported* or *statistical* fires is not covered in this report.

The large array of variables influencing the ignition of forest fuels by lightn is illustrated in figure 1. We feel that a useful estimate of the number of expecte ignitions can be derived from a model which considers only the following:

1. Area density of cloud-to-ground (CG) lightning
2. Storm movement (steering level winds)
3. Precipitation duration
4. Fine fuel moisture
5. Lightning flash characteristics
6. Effective bulk density of fine fuels.

In the following section, we group these variables into components or building blocks to form the structure of a lightning-fire ignition model.

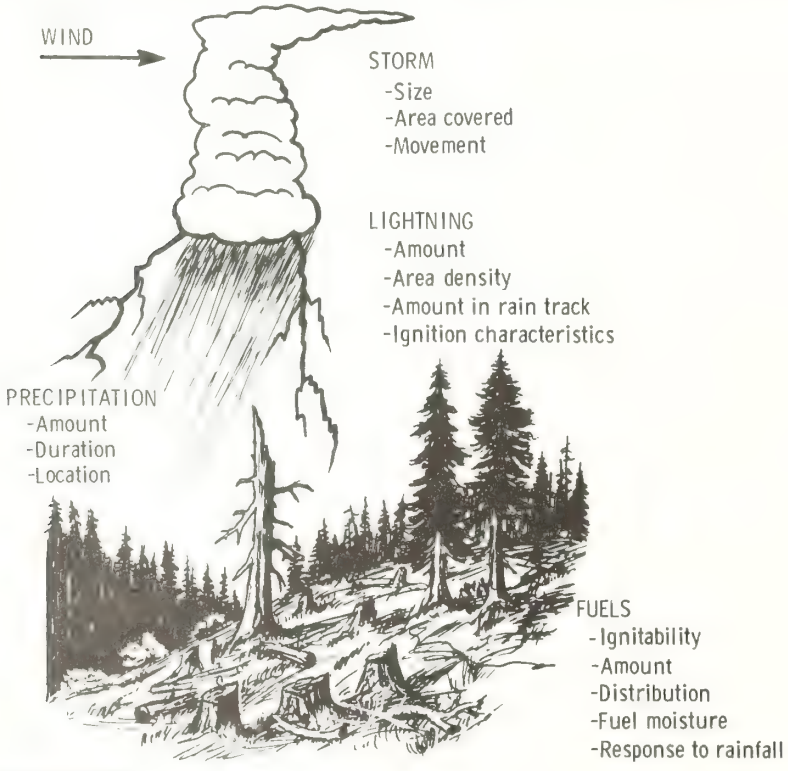


Figure 1.--The lightn fire ignitions envi ment.

[1] A conceptual model for lightning-fire prediction. Unpublished report on file t Northern Forest Fire Laboratory, Missoula, Mont.

COMPONENTS OF THE LIGHTNING-FIRE IGNITION MODEL

Lightning Activity Level

The Lightning Activity Level (LAL) is an index of thunderstorm activity on a basic ale of 1 to 5 (see "How the Model Works, LAL Guide"). The LAL scale and narrative scription format are similar to those given by Deeming and others (1972). We assume at the lightning activity and accompanying meteorological conditions occurring within forecast area of approximately 2,500 mi^2 (6,500 km^2) can be adequately represented by single index value. The LAL index enables a forecaster to predict the general con- tions expected within the forecast area. The LAL descriptors can be used on the ound to identify and label what actually occurs and to convey the information back the forecaster.

The information content of the LAL index is summarized in the LAL Guide (table 1). lightning activity level forecast assigns predetermined values to the following:

1. Number of cloud-to-ground discharges (CG) per 2,500 mi^2 (6,500 km^2)
2. Area covered by radar echoes
3. Area intensity of rainfall
4. Storm size and duration.

ch of the activity levels in the guide provides the forecaster with information to scribe the conditions expected in the forecast area (lightning, cloud development, ecipitation) and for use by the observer in the field to determine the LAL that tually occurred (cloud description, amount and rate of lightning occurrence).

Meteorological Considerations

Fine fuels are highly susceptible to wetting by rainfall. The rainfall accom- nying lightning increases fuel moisture and decreases the probability of ignition. eory predicts that water uptake by fuel is affected more by duration of precipitation an by amount or rate (Fosberg 1972). This concept is used in our model. Calculation the rainfall duration and fuel moisture requires knowledge of the storm size, speed, d duration ("How the Model Works"). Windspeed at cloud level (upper windspeed) is ed to represent storm speed. Other meteorological elements such as air temperature, midity, stability, and surface wind are not considered to play an important part in is ignition model.

Table 1.--*Lightning activity level and its*

Lightning activity level	Cloud and storm development	Rel. freq. on T/S days (percent)	Fraction of area covered by radar echoes of indicated strength: Very light	Light	Moderate	Heavy	Percent of area receiving less than the amount of rain indicated: 0-T	<0.1"	<0.3"	<0.9"
	TYPICAL CLOUD AND PRECIPITATION CONDITIONS (2,500 mi² or 6,500 km² area)									
1	No thunderstorms[1]		No radar echoes				No precipitation			
2	Few building cumulus only occasionally reaching cumulus congestus stage; single CB in forecast area. Visual tops: <30,000 ft (9,100 m) m.s.l.	10	0.1	<0.1			90	91	100	
3	Scattered cumulus to cumulus congestus; widely scattered CB's; cloud-to-ground lightning averaging 1 to 2 per min. max.	35	.2	.1	0.05		70	90	98	100
4	Growing cumulus and cumulus congestus stage over 1/10 to 3/10 of the area; scattered cloud-to-ground lightning in area averaging 2 to 3 per min. max.	35	.2	.1	.05		65	80	95	100
5	Cumulus congestus common over area, occasionally obscuring the sky; moderate to heavy rain associated with CB's; light to moderate rain preceding and following lightning activity. Lightning flashes occurring steadily at some place in or during storm period; maximum CG flash rate greater than 3 per min.	18	.3	.1	.05	0.02	50	75	85	100
6	Scattered towering cumulus with a few at thunderstorm stage; very limited horizontal extent; high bases (15,000 to 17,000 ft m.s.l.). Virga in most prominent hydrometeor form. Lightning flash rate is low, averaging less than 1 to 3 per 5 min. period each storm.[2]	<2								

Lightning activity	Maximum radar echo height, m.s.l.: Feet	Meters	Cloud-to-ground lightning per 2,500 mi² (6,500 km²)	Occurrence rates, maximum: CG/5 min.	CG/15 min.	Aver. rate/min.
	LIGHTNING - AMOUNT AND RATE					
2	<28,000	<8,500	20	--	--	--
3	26,000 - 32,000	7,900 - 9,700	40	0-10	0-17	1-2
4	30,000 - 36,000	9,100 - 11,000	80	4-19	6-32	2-3
5	>36,000	>11,000	160	9-32	19-77	3
6 (See text for explanation)						

[1] In most general terms, 2 days out of 3 will not be thunderstorm days during a typical fire season in the mountainous areas of the western continental United States.

[2] Used with red flag warnings of [illegible]

Ignition

Lightning-caused fires originate almost exclusively in fine fuels, particularly conifer duff and litter under trees, and in so-called "punky wood" found in snags and in crowns of some living trees (Taylor 1969). These fuels fall into the 1 hour timelag category of the NFDRS, and can be assigned a heat of ignition that depends on the fuel and the amount of water (fuel moisture) present. As the fuel is heated during the ignition process, this water must be evaporated (at least from the surface layer) before ignition can take place. The quantity of heat required to ignite a unit area of fuel depends on the heat of ignition of the fuel per unit mass, the amount of fuel per unit volume (bulk density), and the fuel moisture. Bulk densities of the fine woody fuels used in the model calculations have values ranging from 2 to 12 lb/ft^3 (0.03 to 0.192 g/cm^3). These are much higher fine fuel bulk densities than those used for fuel loading in fire spread models where densities are averaged over a large area (see Table 5).

A lightning flash to ground (CG) consists of several sequential events; among these are the "return strokes." The return strokes, surges of current in the channel, carry the flash of light and thunder. In about 20 percent of these CG flashes, an event called the "long continuing current" (LCC) will be present. The LCC has been shown to be highly likely to ignite most lightning-caused forest fires (Fuquay and others 1967, 1972). Thus, the LCC event is included as an important part of our model ("How the Model Works, Ignition Probability").

We now have the fuel, litter and duff, and the "match," the LCC event. The LCC has a wide range of energies, and all will not supply sufficient energy to ignite the fuel. We must, therefore, have an ignition criterion--a way to designate if ignition has taken place. Our model uses a very simple approach. If the energy supplied by the LCC is greater than the amount required to ignite the fuel, an ignition occurs. The model relates this ignition criterion to storm, lightning, and fuel characteristics.

Model Structure

Figure 2 is a simplified diagram of the model. The inputs are:

- LAL, giving the number of expected discharges, the storm size, and the duration of the lightning activity

- speed of the storm

- initial fine fuel moisture

- fuel bulk density.

We use these inputs, together with what we know about the wetting of fuels and the nature of the LCC, to predict the probability that a discharge will cause ignition. This probability is combined with the total number of discharges expected in a given area to give the number of expected fire ignitions in that area. The following section covers the calculations in detail.

LIGHTNING IGNITION MODEL

(Conceptual Structure)

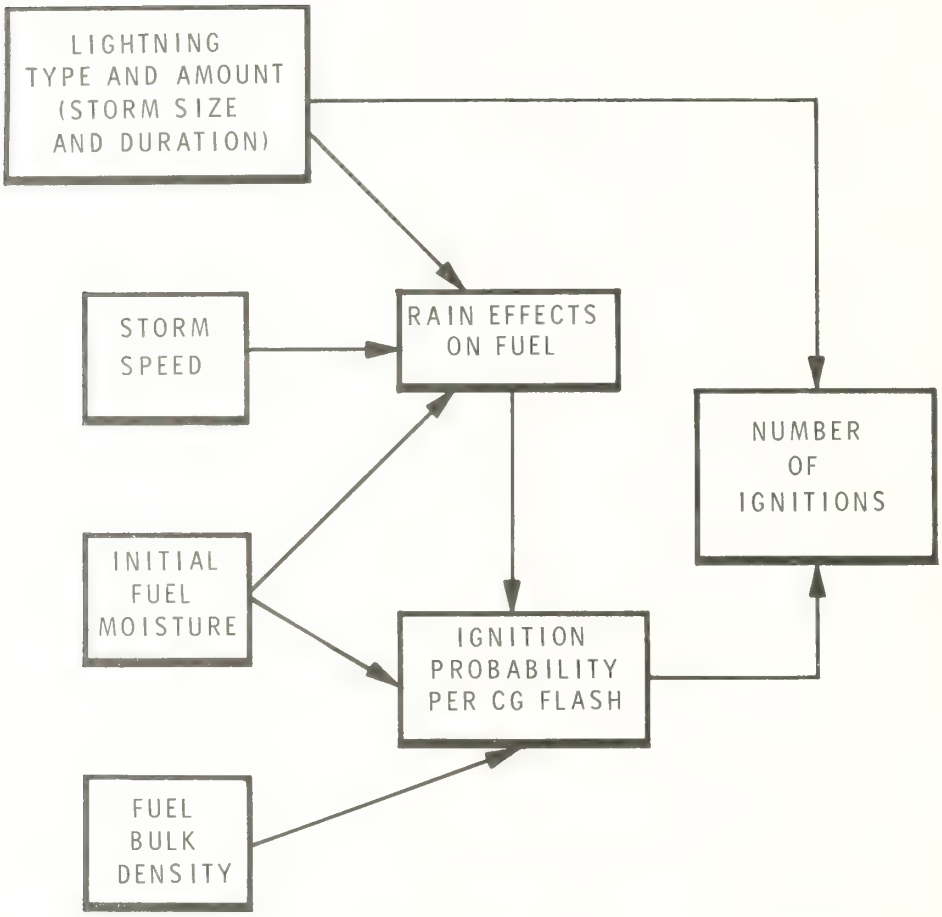

LIGHTNING TYPE AND AMOUNT (STORM SIZE AND DURATION)
STORM SPEED
RAIN EFFECTS ON FUEL
NUMBER OF IGNITIONS
INITIAL FUEL MOISTURE
IGNITION PROBABILITY PER CG FLASH
FUEL BULK DENSITY

Figure 2.--Lightning-fire ignition model (conceptual structure).

HOW THE MODEL WORKS

Lightning Activity Level Guide

The LAL is an index, ranging in steps from 1 to 5, used to describe a generalized daytime thunderstorm condition within a specified forecast area (LAL 6, a special case is covered under "Precipitation Amount and Area Coverage"). In most cases, the forecast areas are designated by the National Weather Service Fire-Weather Forecast Offices in their annual operating plan. Forecast areas vary considerably in size and shape.

The basic and smallest area for which a forecast [illegible] 0 miles on a side (about 6,500 km^2). The values given in the LAL Guide are for each ,500 mi^2 unit within a forecast area. When lightning occurrence or storm coverage is bserved in the field, the observed values should be adjusted to this same area. Light- ing observed over about a 28-mile radius (45 km) would correspond to the 2,500 mi^2 orecast unit.

In general practice, the forecast LAL is used to calculate the maximum number of *ew* ignitions to be expected in the forecast area for the period of the forecast. In he NFDRS, the number of holdover or "sleeper" fires is based on the LAL's that actu- lly occurred on previous days. For this reason, an LAL forecast should always be egarded as conditional. It must be confirmed or corrected before being used for hold- ver fire calculations on subsequent days.

For example, a forecast of LAL 4 for a given forecast area means that *if* LAL 4 ctually occurs, the descriptions within the LAL Guide should be representative of onditions within the forecast area. The descriptors and calculation of ignition oc- urrence are valid only *if* that LAL actually occurs. Thus, there must be field confir- ation of the occurrence of the forecast events.

The LAL Guide has been developed with both forecasting and confirmation in mind. onfirmation can be accomplished by both the forecast office and field personnel. The orecaster can confirm using available radar data (maximum radar height of storms, recipitation coverage and duration), pilot reports, satellite data, and network meteor- logical data. Field personnel can use cloud descriptions, rate and amount of observed G lightning, and area coverage of storms to confirm the LAL.

Now let's look at the LAL Guide and review its structure and the sources of data. he following is an outline of the LAL Guide (table 1):

a. Typical cloud and precipitation conditions

    1. Cloud and storm development

    2. Area coverage of radar echoes

    3. Area amount of precipitation.

b. Lightning - amount and rate

    1. Maximum radar height vs. lightning

    2. Lightning occurrence rates.

The basic data set for the LAL Guide consisted of measured lightning and associ- ted meteorological events during the summer months of 1965, 1966, and 1967 near issoula, Montana. The 3-year period included seasons of high and low lightning ccurrence.

Amount of lightning.--The first step was to estimate the number of CG discharges ssociated with each LAL. To do this, we first found the distribution of CG light- ing per storm day vs. maximum radar echo height. (The visual top of a cloud or hunderstorm system, as might be reported by a pilot, generally exceeds the radar echo eight by about 2,000 ft (600 m). Fuquay (1967) showed that a strong relationship xists between maximum radar echo height and the frequency of lightning. Then, LAL's ere assigned by height classes, with the aid of relative frequency of occurrence data or each radar echo height. In assigning the maximum heights to an LAL index, it was ecognized that a forecast will include a range of values to be expected over the orecast area. Thus, LAL 3 implies that we can expect maximum radar heights to

generally fall in the range 26,000 to 32,000 ft m.s.l. (7,900 to 9,700 m) over the forecast zone. Finally, using radar and lightning data, we developed an estimate of the amount of CG lightning that could reasonably be assigned to each LAL class (tabl

Maximum lightning occurrence rates.--Lightning occurs from coherent groups of clouds or a storm. Usually, the storm will cover less than 500 mi^2. We call this a individual storm. A storm may be made up of one to several cells each in a differen stage of development. Two or more individual storms may occur within the forecast a We can use the *maximum* lightning occurrence rate from one of these storms to estimat the LAL. In general, the maximum rate will occur during the middle one-third of the storm period. Table 1 gives the expected flash rates for each LAL class.

Area-intensity of radar echoes.--An estimate of the fraction of the forecast ar covered by radar echo intensities of very light, light, moderate, and heavy for each LAL class was determined (table 2). Some judgment will be required in applying thes data. The lightning-fire ignition model is designed for the midseason storms when a appreciable number of fire starts can present a management problem. The preseason a postseason storms do not usually result in large number of lightning fires. In the Northern Rockies, the onset of the midseason storm period is early in July. Further south, the season will often begin in late May and early June. The onset of the postseason storms, the fall regime, usually marks the end of the summer fire season.

Table 2.--*Radar echo intensity and coverage, as a fraction of the forecast area covered by radar echoes*

LAL index	Season	Frontal (F)				Non-frontal (AU, U)			
		VL	L	M	H	VL	L	M	H
2	Preseason	0.7	0.5	-	-	-	-	-	-
	Midseason	.1	>.1	-	-	0.1	>0.1	-	-
	Postseason	-	-	-	-	-	-	-	-
3	Preseason	.7	.5	-	-	.2	.1	-	-
	Midseason	.3	.1	.05	-	.2	.1	.05	-
	Postseason	.5	.1	.05	-	.5	.1	.05	-
4	Preseason	.7	.5	.1	-	-	-	-	-
	Midseason	.4	.2	.1	-	.2	.1	.05	-
	Postseason	.5	.2	.1	-	.5	.1	.05	-
5	Preseason	.7	.5	.1	-	-	-	-	-
	Midseason	.4	.2	.1	.05	.3	.1	.05	.02
	Postseason	.5	.2	.1	.05	.4	.2	.1	.05

VL = Very light M = Medium
L = Light H = Heavy

Precipitation amount and area coverage.--Precipitation from midseason summer thunderstorms is usually very spotty. An analysis of radar data (table 3) gives an estimate of how much of a forecast area will receive precipitation and the expected amount. These values should be interpreted as follows: For an LAL 3, 72 percent of the forecast area will have 0 or a trace of precipitation. About 20 percent of the area will receive from 0.01 to 0.09 inch (0.2 to 2.3 mm) of rain. Perhaps only 2 per cent of the area will receive from 0.2 to 0.5 inch (5 to 13 mm). The actual values have been rounded off for use in the LAL Guide.

Table 3.--*Precipitation amount (inch) and area coverage (percent) for LAL's 1-5.*

Precipitation amount (inch)	Rainfall area coverage: LAL 1	2	3	4	5
			(percent)		
0.9 -0.99					
.8 - .89					1
.7 - .79				1	
.6 - .69				1	1
.5 - .59				1	
.4 - .49			1	1	6
.3 - .39			1	1	
.2 - .29			1		5
.1 - .19			5	10	
.01- .09		9	21		27
Trace		12	14		
0		79			34

The high-level thunderstorm (LAL 6).--The high-level dry thunderstorm (LAL 6) is special situation not fully covered by this report. We know that this type of storm, hile relatively rare, can present a severe fire problem. Also, at the present time, he forecast of such storms is always accompanied by a red flag warning issued by the orecaster. The determination of the appropriate values for calculating the fire load ssociated with these storms will require additional study and development. In the nterim, the lightning activity for LAL 3 of 40 CG discharges should be forecast. The ack of precipitation associated with LAL 6 is handled within the model structure.

The term "high-level thunderstorm" should be reserved for the situation where ufficient moisture and instability for thunderstorm initiation are found in the upper evels only. Cloud bases in the Northern Rockies will be at the 15,000 to 17,000 ft about 4,600 to 5,200 m) levels. The thunderstorm activity is generally triggered by he advection of cold air aloft, an upper cold front passage, or widespread vertical otion. This situation is often preceded by *altocumulus castellanus* in the early to idmorning hours. The actual speed of storm movement varies considerably, from near tagnant conditions to rapidly moving systems. The local cells may show considerable recipitation in the form of virga, but virtually no precipitation reaches the ground rom the high bases. Strong downdrafts may develop as the rain evaporates below cloud ase. If the downdraft reaches the ground, strong erratic surface winds may result.

In situations with relatively high moisture content at all levels, storms may be riggered by the same mechanisms. However, bases will be generally lower and consider- bly more moisture will reach the ground. This situation would be better described y LAL's 2 or 3.

Rainfall Effect on Fuel Moisture

Rainfall has a major influence on lightning-fire ignition because it occurs along ith lightning and immediately affects the moisture content of fine forest fuels. Fine uel moisture is a predominant factor in the ignition of fire and was therefore made a omponent of the model. Although other meteorological elements such as temperature, umidity, and wind are also involved, they are only briefly considered here.

How rainfall produces a rapid, predictable increase in fine fuel moisture is described in a recent theory by Fosberg (1972). It states that water uptake by wood is limited by the rate that moisture can be transferred from the surface to internal layers of the fuel. Therefore, the final fuel moisture depends on the *time* that the fuel surface is exposed to precipitation rather than the rate or total amount of precipitation. Also, moisture loss is quite rapid following the end of precipitation. Following this theory, we use rainfall *duration* in our model, instead of rainfall amount or rate, and disregard any day-to-day carryover effect of rain on fuel moisture. The duration of precipitation, as used in the model, corresponds to periods of continuous lightning activity. Even though lightning strikes at random times during a rainfall, we are assuming that the fuel has reached its final moisture value before "allowing" it to be struck. This may mean a very slight underestimate of the total ignition probability.

Rainfall duration.--An estimate of rainfall duration at a point on the ground can be obtained by finding the ratio of storm size to storm speed. Storm size refers to the core of the cloud (radar echo) that produces lightning and precipitation, and not to the overall visible extent of clouds making up the storm. Our model relates storm size to each of the LAL's. This was done by using data where the horizontal storm dimension and corresponding maximum radar echo heights were given for North Dakota (Miller and others 1975) and Montana (unpublished data[2]). These maximum heights were then matched with the maximum radar echo heights for each LAL class to give us an LAL-to-horizontal storm dimension relationship. Thus, a prediction or declaration of an LAL automatically selects a maximum storm dimension in the model.

It is known that lightning strikes the ground both inside and outside of the rain area (or track) on the ground, and observations indicate that a total lightning strike zone 4 miles wider than the corresponding storm width is appropriate for model use. The storm size (rainfall track width) and lightning zone width corresponding to each LAL class are given in table 4.

Table 4.--*Storm size and lightning zone size as defined in figure 3*

LAL	Storm size		Lightning zone size	
	Miles	Kilometers	Miles	Kilometers
2	3	4.8	7	11.2
3	4	6.4	8	12.8
4	5	8.0	9	14.4
5	7	11.2	11	17.6

We also need to know the speed of a storm to calculate rain duration. There exists an upper air level (steering level) where the velocity of the basic flow bears a direct relationship to the velocity of clouds embedded in the flow. For example, the best steering level over the Northern Rockies is the 14,000 ft (4,300 km) level (Osborne and others 1953). For the 49 cases tested (radar echo movement), the 14,000 ft (4,300 km) echo speed was within 10 knots of the windspeed 90 percent of the time. Upper windspeed data available from the National Weather Service can be used to calculate windspeed at this level. Rain duration can then be computed as the ratio of storm size to storm speed.

[2]Unpublished data on file at the Northern Forest Fire Laboratory, Missoula, Mont.

Rainfall effect on fine fuel moisture.--The effect of precipitation on the fine fuel moisture content can be determined by the following equation (Fosberg 1972):

$$\delta m/\Delta m = 1 - \zeta\, e^{-t/\tau m}$$

where:

δm is the actual moisture content change

Δm is the potential change

ζ is a varying parameter, depending on t/τ_m

t is the time period involved (rainfall duration)

τ_m is the particle moisture timelag.

$\delta m/\Delta m$ can be given as:

$$\delta m/\Delta m = \frac{FMF - FMI}{FMS - FMI}$$

where:

FMF is the final fuel moisture content

FMI is the initial moisture content

FMS is the moisture content at the wetted surface of the fuel, thus:

$$FMF = FMI + (FMS - FMI)\,(1 - \zeta\, e^{-t/\tau_m}).$$

Fosberg's theory was developed for dead cylindrical fuel such as logs, stems, and twigs. We apply the theory to any fine fuel that may be ignited by lightning, including fuel on trees and snags, or in duff and litter layers. Also, since we are dealing only with fine fuels, we limit the values of FMF to those fuels with timelag periods of 1 hour or less. This means that we can use a 1-hour moisture timelag value for τ_m, set ζ equal to 1, and assign FMS a value of 76 percent (after Fosberg 1972). The initial fuel moisture (FMI) can be obtained from current observations (Deeming and others 1972) while the rainfall duration (t) is obtained as given above.

Rainfall area.--We have shown (fig. 3) that we consider two areas within each storm: a rainfall area and a lightning area. We included two areas in the model because lightning hits both inside and outside of the storm rainfall area. Obviously, the ignition probability inside the rainfall area is less than that outside the rainfall area.

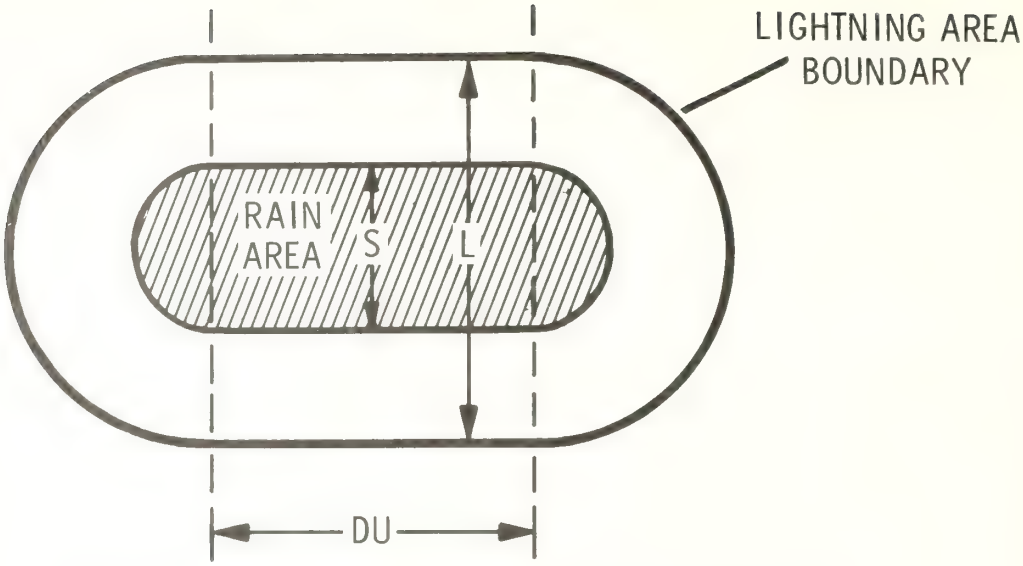


Figure 3.--Idealized shape of lightning and rain area.

D = Lightning activity duration
U = upper windspeed
S = storm size (rainfall area)
L = lightning area

In order to calculate the different ignition probabilities, we need to know the lightning activity duration and the relative size of the area with rainfall and of the dry zone outside. (Lightning activity duration refers to the continuous periods of lightning activity in a general area.) For modeling purposes, information was taken from data obtained in western Montana (Fuquay and Baughman 1969). The following tabulation gives a representative storm duration from each LAL:

LAL	*Lightning Activity Duration (Minutes)*
2	150
3	174
4	200
5	230

The idealized shape of an electrically active storm (considering a circular storm moving along with the wind) is that of a racetrack with an infield. Lightning hits the total area (racetrack plus infield) while rain falls only in the infield. Figure 3 shows the racetrack concept.

The fractions of the area with rain (FI) and without rain (FO) are computed as follows:

$$FI = \frac{4DUS + \pi S^2}{4DUL + \pi L^2}$$

$$FO = 1 - FI.$$

A flow diagram (fig. 4) shows the steps necessary to obtain a final fuel moisture (FMF) due to rainfall and the fractional size of the area with (FI) and without (FO) rain. This information will be combined later with ignition probabilities to calculate an overall average probability.

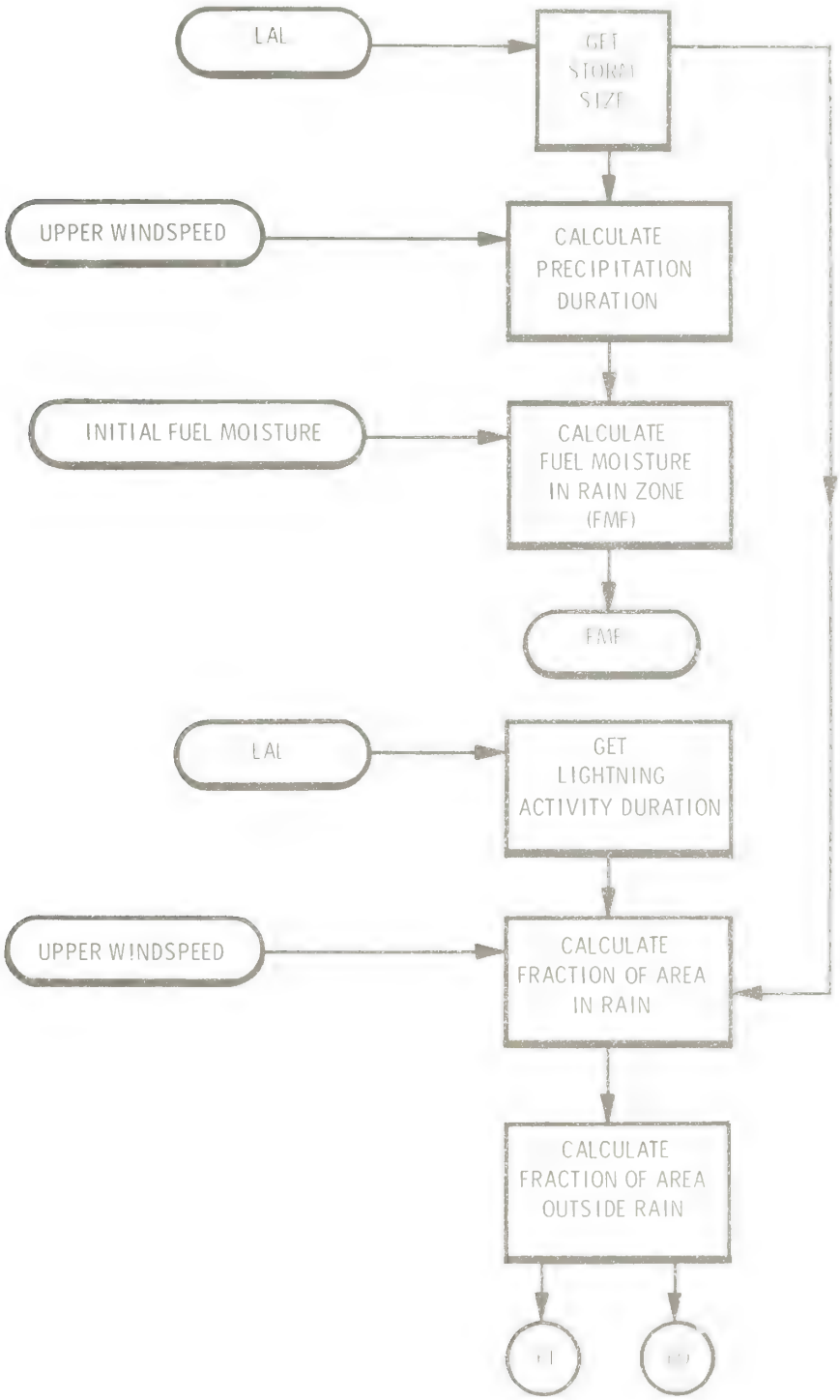


Figure 4.--Final fuel moisture and rain fraction determination.

Other meteorological elements.--Other meteorological elements such as temperature, humidity, and wind are also part of the lightning-fire problem. Air temperature and humidity are included indirectly in our model through the use of an initial fuel moisture content. The model is presently set up to use the 1 hour fine fuel moisture as an initial condition. The surface wind is not now included as a factor in ignition. We may need to change our model with regard to these elements later on.

Ignition Probability

We need to know the probability that a CG discharge will ignite the fuel through which it passes. We have shown that ignition depends on the characteristics of the fuel, its moisture content, and the nature of the lightning flash. The basic criterion for ignition is that

$$E_c > E_{ig}$$

where:

E_c = the energy density of the lightning channel

E_{ig} = the energy density required to ignite a volume of fine fuel.

Here, we shall develop an expression for the probability that a CG discharge will have an energy density $E_c > E_{ig}$.

First we consider E_{ig} for fine fuels. The energy density necessary to ignite a volume of fuel is taken from Anderson (1969), as well as Frandsen (1973), Stockstad (1975), and Rothermel (1972), and can be expressed as:

$$E_{ig} = (\varepsilon)\ (RHOB)\ (Q_{ig}) \qquad (1)$$

where:

Q_{ig} = ignition energy per unit mass of fuel

RHOB = the fuel bulk density

ε = an efficiency factor, $\simeq 1$ for fine fuels.

This expression can be put in terms of fuel moisture (FM) and bulk density (RHOB):

$$E_{ig} = RHOB\ (170 + 6.20\ FM)\ cal/cm^3 \qquad (2)$$

RHOB, as used in our model, refers to concentrations of fine fuels such as duff and litter, standing punky wood, etc. It is not the average fine fuel bulk density as used in the NFDRS.

These "spot" bulk densities of various fine fuels can be obtained from Brown (1970) and Mader (1953). Typical values for those fuels likely to be struck are given in table 5. The model treats RHOB as a continuous variable.

Table 5.--*Bulk densities for some of the NFDRS fuel models. After Brown (1970, private communications); Mader (1953)*

Forest fuel type	NFDRS fuel model	1966 [illegible]
Tundra	S	2
Western annual grass	A	2
Pine-grass	C	4
Western long-needled conifer	U	4
Short-needle (normal dead)	H	8
Short-needle (heavy dead)	G	8
Alaskan black spruce	Q	8
Sagebrush-grass	T	2
Eastern pine (plantation)	P	4

We next need to know the probability of the energy density in an LCC discharge being sufficient to cause ignition or:

$$p(\text{Ignition/LCC}) = p(E_c \geq E_{ig}). \qquad (3)$$

The energy density (E_c) in the lightning channel must be calculated from the electrical heating in the channel, the channel radius, and the duration of the discharge, or:

$$E_c = \frac{Q_c d}{\pi r^2} \times 10 \quad \text{cal/cm} \qquad (4)$$

where:

Q_c = channel power dissipation per unit length

d = duration of the discharge, milliseconds

r = radius of the channel, cm.

To find the channel power, we have:

$$Q_c = FI \text{ watt/cm} \qquad (5)$$

where:

F = the electric field

I = the current.

King (1962) found a constant electric field along long vertical arcs of 10 V/cm (Volts per centimeter).

Brook and others (1962) and Williams and Brook (1963) have measured continuing currents and their duration. A good fit to these data was:

$$I = 44.7d^{0.1787}. \tag{6}$$

The range of currents was from 50 to 500 A.

From (5) and (6), and King's value for F:

$$Q_c = 107d^{0.1787} \text{ cal/cm-s}. \tag{7}$$

The total energy release per cm of channel is Q_c $(d \times 10^{-3})$.

A channel radius value has been calculated from considerations by Cobine (1958) and Finkelnburg and Maecker (1956); this value is approximately 1 cm, hence (4) becomes:

$$E_c = 0.054d^{1.1787} \text{ cal/cm}^3. \tag{8}$$

Statistics on LCC durations are available from measurements in western Montana (Fuquay 1974). Using these, we have applied a Beta P probability distribution (Miell and Johnson 1974) which gives the fraction of continuing currents which can be expected to yield an energy exceeding E_{ig}:

$$p(E_c > E_{ig}) = (1 + (E_{ig}/\beta)^{\theta})^{-\alpha} \tag{9}$$

where:

$\alpha = 1401.647$

$\beta = 2822.164$

$\theta = 1.442.$

The ignition criterion is that the available energy from a given LCC event be greater than that required by the fuel for ignition, assuming that all LCC energy is transferred to the fuel. Since the available energy density has a probability, so must the ignition. We call this the ignition probability per LCC event. It is a function of fuel moisture and bulk density, and can be obtained from (2) and (9):

$$P_{ig} = \left[1 + \left(\frac{\text{RHOB } 170 + 6.20 \text{ FM}}{\beta} \right)^{\theta} \right]^{-\alpha}. \tag{10}$$

Figure 5 gives curves of (10) as a function of fuel moisture for values of bulk density from table 5.

Because the LAL gives the number of CG discharges without regard to the presence of an LCC event, we must modify the probability from "per LCC" to "per CG"; this is done by multiplying by the LCC/CG ratio. For Rocky Mountain thunderstorms this ratio is about 1 in 5. The flow chart for the entire ignition probability calculation is shown in figure 6.

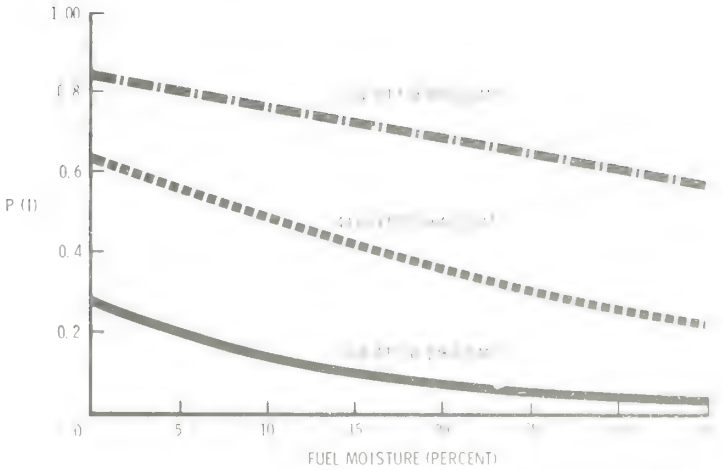


Figure 5.--Ignition probability vs. fuel moisture for the bulk densities of table 5.

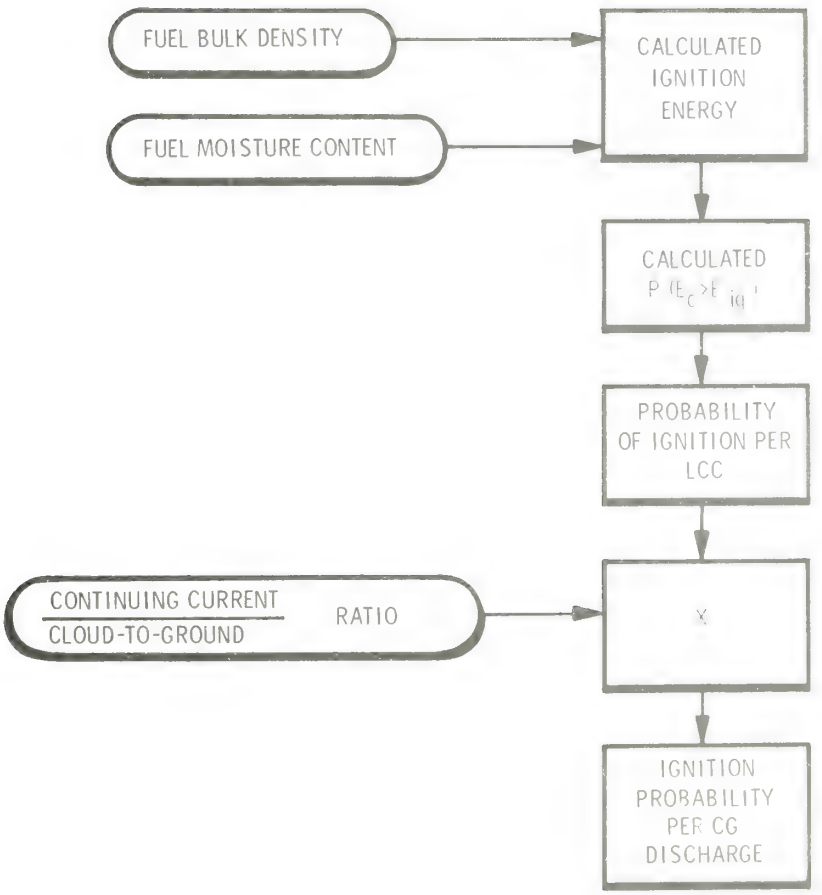


Figure 6.--Ignition efficiency flow chart.

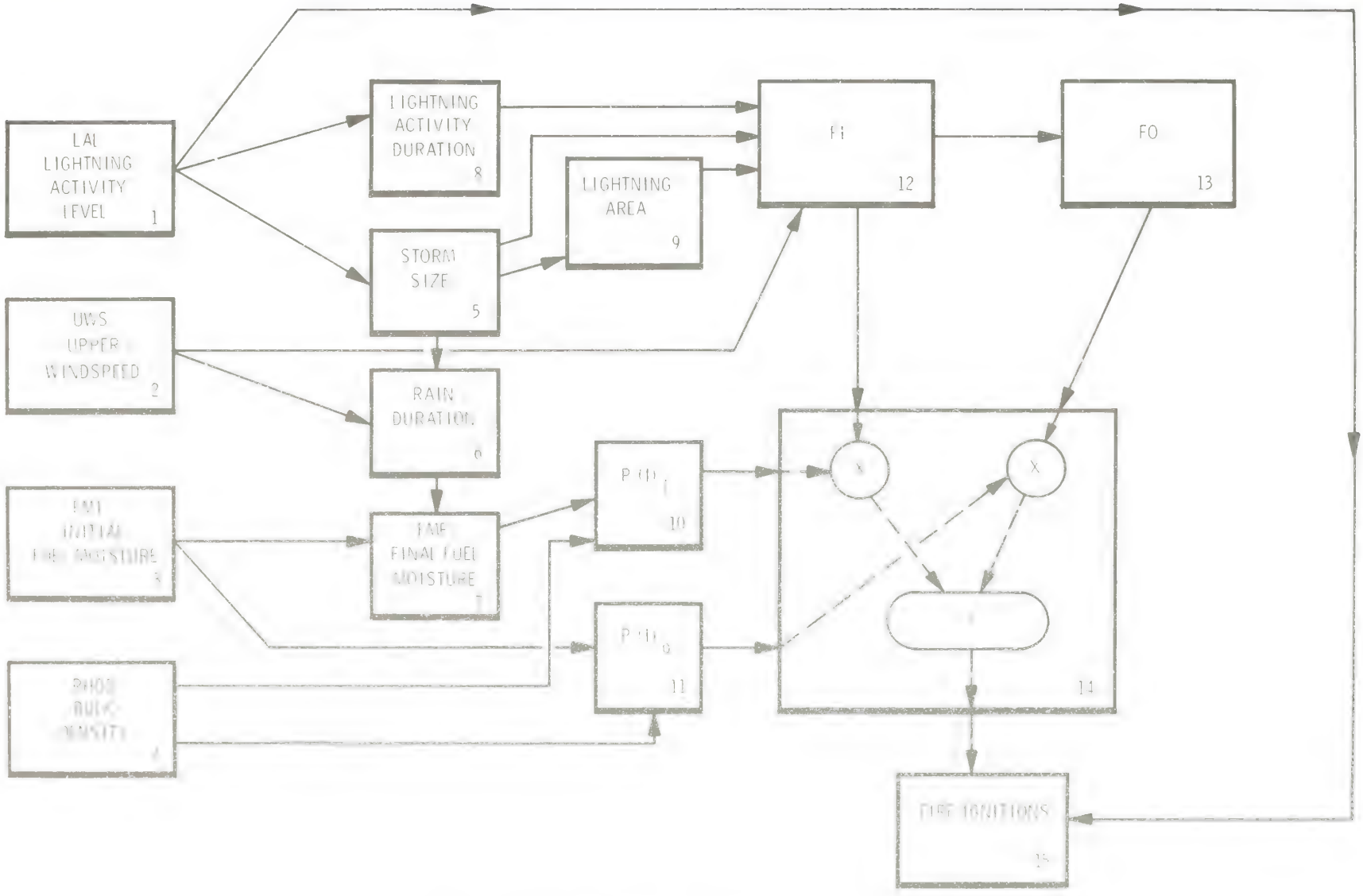
The Model

In the previous sections, we discussed the lightning activity level, behavior o fine fuels with rainfall, and ignition probability per CG discharge. These will now be combined to yield a probable number of ignitions in a given area. Figure 7 is a flow chart expressing this combination.

Each block is numbered; we shall discuss the flow chart in terms of the function of these blocks (note that there are four input blocks, 1, 2, 3, 4, and one output block, 15):

1. LAL--Lightning Activity Level; forecast or determined by direct observations,
2. Upper Wind--the steering level wind,
3. FMI--the initial one hour timelag fuel moisture,
4. RHOB--the bulk density of litter, duff, grass, or other fine fuels into whic the discharge may take place; again, not the average fine fuel bulk density as used for loading calculations, but rather the "spot" bulk density under trees,
5. Storm Size--an empirically determined effective rain track width,
6. Rain Duration--the storm size (5) divided by the upper wind (2) giving the rainfall duration at a spot on the ground,
7. FMF--final fuel moisture,
8. Lightning Activity Duration--the empirically determined time during which lightning and rain occur,
9. Lightning Area--the total area where lightning may strike,
10. $P(I)_i$--probability of ignition in rain,
11. $P(I)_o$--probability of ignition outside of rain,
12. FI--the fraction of the total area covered by rain,
13. FO--the fraction of total area covered by lightning outside the rain track.
14. A combinatorial block--(fraction inside rain) × (probability of ignition inside rain) + (fraction outside rain) × (probability of ignition outside rain) = ignition probability per LCC,
15. Fire ignitions per 2,500 mi^2 (6,500 km^2)--the expected number of CG discharg per 2,500 mi^2 (6,500 km^2) (obtained from the LAL) is multiplied by 0.2 (to g expected number of continuing current discharges); then multiplied by the probability that any given LCC discharge will ignite the fuel; the resulting number is the number of expected ignitions per 2,500 mi^2 (6,500 km^2) (figure

Note: For the high-level thunderstorm (LAL 6), we use the LAL 3 lightning activity o 40 CG, set FI = 0 and FO = 1, and LCC/CG = 1.


LAL
LIGHTNING
ACTIVITY
LEVEL
1
LIGHTNING
ACTIVITY
DURATION
8
LIGHTNING
AREA
9
STORM
SIZE
5
Fi
12
FO
13
UWS
UPPER
WINDSPEED
2
RAIN
DURATION
6
FMI
INITIAL
FUEL MOISTURE
3
FMF
FINAL FUEL
MOISTURE
7
P(I)
10
P(I)
11
RHOB
BULK
DENSITY
4
X
X
14
FIRE IGNITIONS
15

REMARKS

We have described a model for predicting lightning-fire ignition based on physic processes of woody fuel ignition; however, the strong influence of chance events is a integral part of the model.

The model is rudimentary. Little information is available on ignition of woody fuel by arc discharge. Further, several characteristics of lightning discharges had to be estimated. Little is known about the spatial distribution of fine fuel charact istics, such as bulk density and moisture content.

Much of the information on thunderstorms and lightning used in developing this model was gathered in the Northern Rocky Mountain region. However, comparison with c areas gives us confidence that the basic model can be adapted for use in the western United States, western Canada, and parts of Alaska.

In describing the model, we have emphasized use of a 24-hour prognosis of weathe events. The model also applies in real time when used with current fine fuel and lig ning storm data.

The complete program for the model in Fortran IV computer language is available from the authors at the Northern Forest Fire Laboratory.

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GLOSSARY

CG	Cloud-to-ground lightning discharge or flash consisting of one or more strokes
LCC	(long) continuing current - an arc-like discharge sometimes accompanying one stroke in a flash
D	Duration of lightning activity (during a given storm)
FM	Fuel moisture
FMI	Initial fuel moisture
FMF	Fuel moisture after rainfall
FMS	Moisture content at wetted surface of the fuel
RHOB	Fine fuel bulk density (ρ_b)
U	Storm speed (windspeed at 14,000 feet or about 4,300 meters)
S	Width of rainfall track on the ground
L	Width of zone in which lightning strikes
FI	Fraction of total lightning struck zone which also has rainfall
FO	Fraction of total lightning struck zone with no rainfall
E_c	Energy density in LCC channel
E_{ig}	Energy density required for fuel ignition
Q_{ig}	Ignition energy per unit mass of fuel
Q_c	LCC channel power dissipation per unit length
d	Duration of LCC discharge
r	LCC channel radius
F	Electric field in LCC channel
I	Current in LCC arc
P_{ig}	Ignition probability per LCC

Fuquay, Donald M., Robert G. Baughman, and Don J. Latham.
1979. A model for predicting lightning fire ignition in wildlands fuels. USDA For. Serv. Res. Pap. INT-217, 21 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

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CONTENTS

INTRODUCTION 1

DELINEATING MONTANA FOREST REGIONS 3

FOREST REGION DESCRIPTIONS 9

Northwestern Montana Forest Region 11
West-Central Montana Forest Region 13
North-Central Montana Forest Region 15
Central Montana Forest Region 17
Southwestern Montana Forest Region 18
South-Central Montana Forest Region 20
Southeastern Montana Forest Region 21
Northeastern Montana Forest Region 22

RESEARCH AND MANAGEMENT APPLICATIONS 23

PUBLICATIONS CITED 25

APPENDIX A--DISTRIBUTION OF KEY TREE AND UNDERGROWTH SPECIES IN MONTANA 31

APPENDIX B--NUMBER OF SAMPLE PLOTS (PFISTER AND OTHERS 1977) BY HABITAT TYPE, PHASE, AND FOREST REGION IN MONTANA 33

APPENDIX C--NATIONAL FORESTS, INDIAN RESERVATIONS, AND NATIONAL PARKS WITHIN EACH FOREST REGION IN MONTANA 35

RESEARCH SUMMARY

The author categorizes forest vegetation across Montana into eight geographic subdivisions called "forest regions." The regions correlate the influence of climate and general topography to forest vegetation--including the distributions of tree and undergrowth species and forest habitat types. The vertical zonation of forest series (based on the potential climax tree species) also differs from one region to the next. Regional boundaries were fitted to distributions of certain tree and undergrowth species, habitat types, and natural climatic barriers such as the Continential Divide and broad grassland valleys that separate forest environments.

(1) The northwestern Montana forest region has major representation by Pacific Coast species such as Thuja plicata and Clintonia uniflora; its climate is strongly influenced by moist maritime airmasses. (2) The west-central region has a generally drier Pacific-influenced climate and only small amounts of Pacific Coast species; however, it has major representation of intermountain plants like Larix occidentalis and Xerophyllum tenax.

(3) North-central Montana lies in the severe climate of the "chinook wind belt" along the east slope of the Continental Divide. It is distinguished by being too cold for Pinus ponderosa, but having extensive Populus tremuloides groves and Pinus flexilis woodlands. (4) The central Montana forest region has a less severe continental climate and it supports the east-side form of Pinus ponderosa at lower elevations. However, both coastal and intermountain species are essentially absent from its mountain forests.

Both the (5) southwestern and (6) south-central forest regions have high base elevations and are without Pinus ponderosa. The former region's forests are generally drier than the latter's and often have sparse undergrowth. (7) Southeastern Montana differs from previously mentioned regions in not having prominent mountains. It has extensive Great Plains Pinus ponderosa forests. (8) Northeastern Montana is a Great Plains area having no forest, except for Populus deltoides groves along major streams.

The regions may be useful as a biologically based stratification for forest research and forest management studies.

INTRODUCTION

This report describes Montana's forests by geographic subdivisions called "forest regions." It emphasizes patterns in species composition (trees and undergrowth) and the relationship of these patterns to climate and topography. The interpretations are based on field experience and data collected during a recent forest habitat type classification (Pfister and others 1977).

There are two primary reasons for delineating the forest regions of Montana. First, the regions serve as a geographic reference for describing patterns of forest vegetation across the State. Second, delineating the regions contributes to regional classifications that are being developed from a national perspective (Bailey 1976, 1978). The geographic subdivisions discussed in this paper are based on the distribution of forest vegetation in relation to climate (as influenced by topography). Thus, these subdivisions are proposed for use only for interpretations related to forest vegetation.

After reviewing definitions provided in Kuchler (1973) and Bailey (1976), the term "forest region" seemed most appropriate for use here. "Region" is a general term that does not necessarily specify a level in the land classification hierarchy, and the term "forest region" has been applied in Canada (Rowe 1972). ("Province" was also considered, but it has a more precise hierarchical definition related to the dominant vegetative types in an area, or to physiography; thus, some of Montana's forest regions occur within grassland provinces.)

Other regional divisions of Montana have been developed from different types of information to meet different objectives. Schmidt and Dufour (1975) emphasized geomorphology in designating six regions within Montana. Those regions were used in assessing research natural area needs from the following viewpoints: forest vegetation, grass and shrubland vegetation, geology, zoology, and aquatics. Crowley (1972) depicted seven major environmental regions within Montana based on characteristics of human environments, including landforms, climate, and elevational zonations of vegetation.

Still others (Kuchler 1964; Payne 1973; Ross and Hunter 1976) have provided maps of Montana's natural vegetative types; but the maps are not focused on regional variation in forest vegetation. In contrast to these references, the Montana "forest regions" proposed here delineate rather broad areas having similar zonation in forest vegetation. These forest regions have general similarities to the forest districts designated by the early Montana botanist, Kirkwood (1922), for describing forest distribution in the Northern Rocky Mountains.

During the Montana forest habitat type study (Pfister and others 1977), 1,500 stands were sampled "subjectively without bias" (Mueller-Dombois and Ellenburg 1974). The stands represent a spectrum of mature forest communities and sites in each mountain range and forested area of the State. As the habitat type classification was being developed from these data, it became obvious that distributions of many tree and undergrowth species (and thus the distributions of the habitat types) are strongly correlated

to patterns of geography and climate within Montana. It became evident that the State could be subdivided into several relatively homogeneous forest regions based on the data, field observations, and information on plant species distributions (Herbarium collections at the University of Montana, Missoula; Montana State University, Bozeman; the USDA Forest Service Forestry Sciences Laboratory, Missoula; personal interviews with local foresters and botanists (see acknowledgments); Booth and Wright 1966, Hitchcock and others 1955-1969, Little 1971, 1976).

A map of forest regions (called "geographic subdivisions") was presented by Pfister and others (1977), and a brief account of each habitat type's distribution was given by region. However, the basis for these regions was not discussed; also, Montana's forest vegetation and environments were not described by region. These topics are addressed here.

The Canadian Forest Service (Rowe 1959, 1972) mapped and described "Forest Regions of Canada," which provides a precedent. Rowe (1972) explained that the Canadian regional designations are generalized, with the broad perspective of Canada as a whole, although the statement was made that it would be possible to designate such regions from a detailed knowledge of specific areas if detailed data existed. The latter approach is used here with detailed data from the habitat type study (Pfister and others 1977) as a basis.

Kuchler (1973) discussed techniques for designating ecologically based "regions." He stated that classifications of natural vegetation types and detailed mapping of their distributions are fundamental for establishing such regions. (It appears that the Montana forest habitat type classification along with the sample plots and other distributional data can provide this basic information.) Kuchler (1973) also concluded that vegetation regions should first be designated within a limited study area, such as a State or geographic region, and later expanded to surrounding areas.

DELINEATING MONTANA FOREST REGIONS

Montana's forests are both extensive and diverse. Forest [illegible] of Montana--about 23 million acres according to Green and Setzer (1974)--and substantial amounts of forest are found in all but the northeastern portions of the State (fig. 1). At lower elevations these forests range from luxuriant stands of *Tsuga heterophylla*, *Thuja plicata*, *Pinus monticola*, and other Pacific Coast species in northwestern Montana to open *Pinus ponderosa* woodlands on the Great Plains of southeastern Montana. The high-elevation forests across the Montana Rockies also show substantial variation.

Differences in climate are primarily responsible for geographic variations in the potential climax forest vegetation, expressed in habitat types (Pfister and others 1977). The climatic differences across Montana reflect the greater importance of Pacific maritime airmasses west of the Continental Divide versus continental climatic conditions east of the Divide. Locally, climate (and thus forest vegetation) also is strongly influenced by changes in elevation, aspect, and landform within the Montana Rockies. Soils and underlying geology also affect forest vegetation, but except for certain limestone substrates and extremely rocky sites, the effects do not generally obscure the overriding influence of climate and topography.

The forest regions outlined on figure 1 correlate the influence of climate and general topography to forest vegetation--including the distributions of tree and undergrowth species and forest habitat types and the vertical zonation of forest series (discussed later). Because tree species serve as indicators of climate (Daubenmire and Daubenmire 1968; Pfister and others 1977), their geographic distributions serve as a primary determinant of regional boundaries. (Appendixes A-1 through A-6 illustrate how the distributions of tree species correlate with Montana's forest regions.) Distributions of undergrowth species that have proved useful as indicator plants in major forest habitat type classifications in the Northern Rockies (R. and J. Daubenmire 1968; Pfister and others 1977; and Robert Steele and others[1]), also were used (for examples, see appendixes A-7 through A-10).

It became obvious that many of the tree, undergrowth plant, and habitat type distributions showed similar patterns, and relate to known climatic differences (U.S. Department of Commerce 1971; USDA Soil Conservation Service 1968). Preliminary regional boundaries were drawn to fit these vegetational data. The boundaries then were adjusted slightly to correlate with natural climatic barriers such as the Continental Divide and broad grassland valleys that separate forest environments. Although these regional boundaries were fitted to vegetation data and to topographic barriers as logically as possible, sometimes the general patterns of forest vegetation change gradually over rather broad areas. In these cases, where possible, major topographic features were used for final placement of boundaries. Dashed lines were used to designate regional boundaries in nonforested areas.

The occurrence of the approximately 1,500 sample plots by habitat type and forest region is summarized in appendix B. Plant composition at these forest sites provides basic data for regional boundaries. At a broad level of generalization from this data

[1]Review drafts of "Forest habitat types of central Idaho" (1975) and those of the Nezperce National Forest (1976). Intermt. For. and Range Exp. Stn., Ogden, Utah.

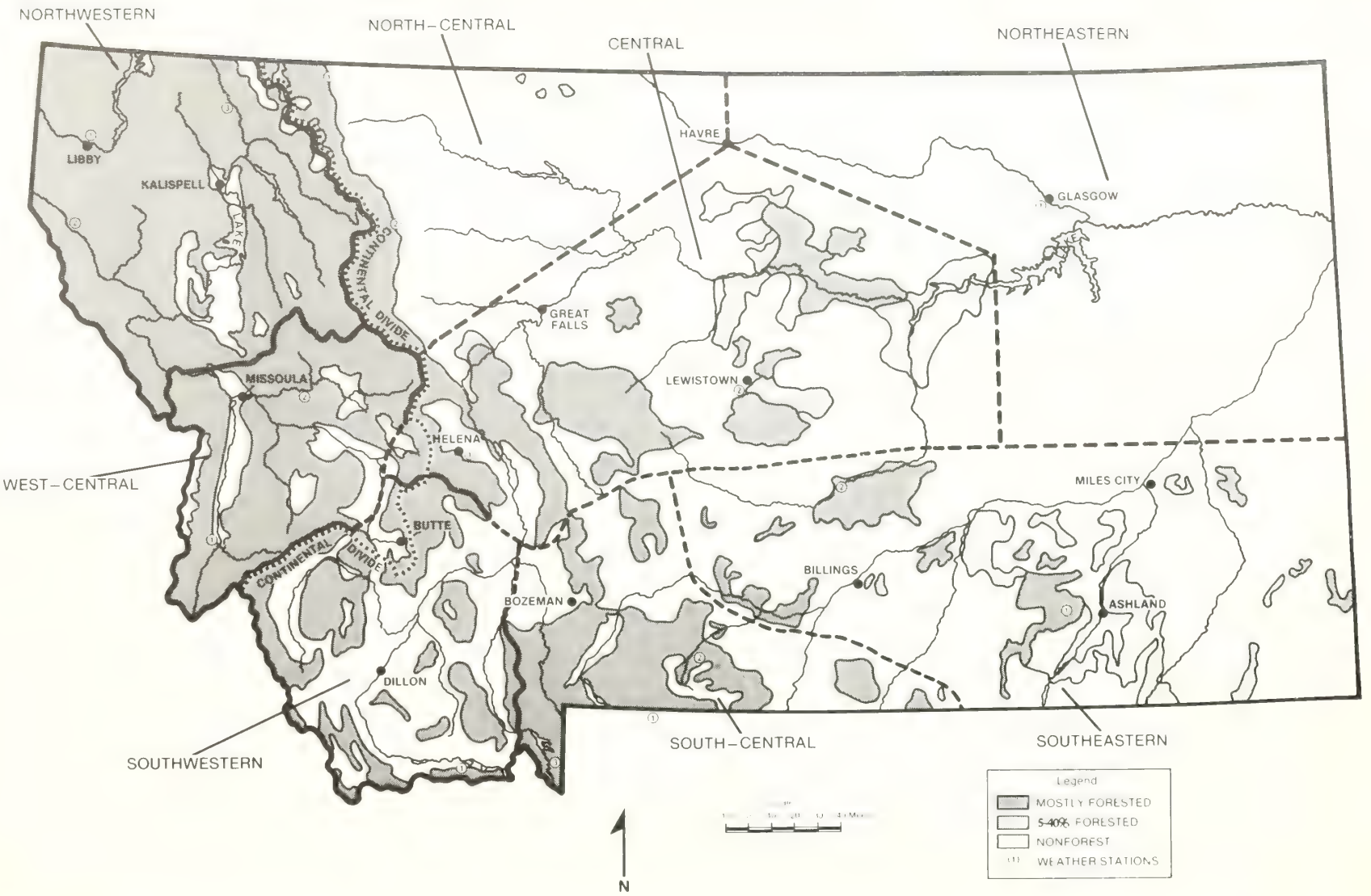

Figure 1.--Montana forest regions and forested areas (from Hutchinson and Kemp 1952, Ross and Hunter 1976, composite satellite photo of Montana, GE Space Systems, Beltsville, Md.) Circled numbers are weather stations listed in table 4.

Table 1.--[illegible]

Series	Forest: North-western	West-central	North-central	Central	South-[illegible]	South-central	South-[illegible]	North-eastern
[illegible]	M	r						
[illegible]	M	m						
Picea	m	r	m	M	m	M		
Pinus contorta	r	m	r	M	M	r		
Pinus ponderosa	m	m	r	M	r	r		
Pinus [illegible]	r	r	M	m	m	r		
Pseudotsuga	M	M	M	M	M	M		
Abies lasiocarpa	M	M	M	M	r	r		

The extent (area covered) of each climax series can be compared--identified by the most shade-tolerant (potential climax) tree species capable of growing on a given site. Table 1 shows which *series* occur in each of the forest regions. For instance, the Pacific Northwest coastal forest types (*Thuja, Tsuga,* and *Abies grandis* series) are of major importance only in northwestern Montana. Low-elevation forest types (*Pinus ponderosa* climax series) associated with dry, inland climates are abundant only in central and southeastern Montana, and are absent or rare in the north-central, southwestern, and south-central forest regions.

Detailed interpretations (from appendix B data) are presented in table 2, which shows the major habitat types in each of Montana's forest regions. Additional interpretations and adjustments were made in developing table 2 from the sample plot data (appendix B). Certain substrate-oriented habitat types (such as *Picea/Senecio streptanthifolius* and *Abies lasiocarpa/Clematis pseudoalpina* h.t. on limestone substrates) were heavily sampled by Pfister and others (1977), and are not as extensive as appendix B implies. Also, certain areas near the border of a forest region were heavily sampled; thereby more plots were collected from certain habitat types than are indicative of the region in general. For instance, several *Abies lasiocarpa/Clintonia* and *Abies lasiocarpa/Xerophyllum* h.t. plots were taken in unusual locations immediately east of the Continental Divide in north-central Montana.

The distribution of various tree species and undergrowth plants serving as habitat type or climatic indicators is presented in table 3 by forest region across Montana. This table is based on the 1,500 habitat type plots, and the field observations and published information on plant distributions cited previously. The distributions of Pacific Coast and intermountain species are useful for differentiating forests of northern Idaho, northwestern Montana, and west-central Montana, but the other forest regions are characterized largely by a lack of these species. ("Intermountain species" applies to plants found most often between the crest of the Cascade Mountains and the Continental Divide.)

Certain widespread species (like *Vaccinium scoparium, Juniperus communis, Arnica cordifolia, Aster conspicuus,* and even *Pyrola secunda*) generally are accompanied by Pacific Coast or intermountain species west of the Continental Divide; farther east the coastal and intermountain competitors drop out. This situation is documented by the changes in habitat types depicted in table 2. For instance, *Pseudotsuga/Juniperus communis, Pseudotsuga/Arnica cordifolia,* and *Abies lasiocarpa/Arnica cordifolia* appear only east of the Divide.

Figure 2 shows a summary of the characteristics of each forest region. The relationship of forest region and National Forest boundaries is shown in appendix C.

Table 2.--*Major habitat types (Pfister and others 1977) in each of Montana's forest regions (See appendix B for more detailed information on all habitat types)*

Habitat type	Forest region						
	NW	WC	NC	C	SW	SC	SE
Pinus flexilis/Festuca idahoensis	.	.	x	x	.	.	.
P. ponderosa/Agropyron spicatum	.	x	.	.	.	.	x
P. ponderosa/Festuca idahoensis	.	x	.	x	.	.	x
P. ponderosa/Symphoricarpos albus	.	.	.	x	.	.	x
P. ponderosa/Prunus virginiana	.	.	.	.	.	.	x
Pseudotsuga/Festuca idahoensis	.	.	.	.	x	.	.
Pseudotsuga/Festuca scabrella	.	.	.	x	.	.	.
Pseudotsuga/Vaccinium caespitosum	x	x	.	.	.	.	.
Pseudotsuga/Physocarpus malvaceus	x	x	.	.	.	x	.
Pseudotsuga/Vaccinium globulare	x	x	.	x	.	.	.
Pseudotsuga/Linnaea borealis	.	x	.	x	.	.	.
Pseudotsuga/Symphoricarpos albus	x	x	x	x	x	x	.
Pseudotsuga/Calamagrostis, Cal. phase	.	x	.	x	x	x	.
Pseudotsuga/Cal., other phases	x	x	.	x	.	.	.
Pseudotsuga/Spiraea betulifolia	.	.	x	x	.	.	.
Pseudotsuga/Arctostaphylos uva-ursi	.	.	.	x	.	.	.
Pseudotsuga/Juniperus communis	.	.	.	x	x	.	.
Pseudotsuga/Arnica cordifolia		.	.	x	x	.	.
Picea/Clintonia uniflora	x	.	.	.	.	.	.
Picea/Physocarpus malvaceus	.	.	.	.	.	x	.
Picea/Galium triflorum	.	.	.	.	.	x	.
Picea/Linnaea borealis	.	.	.	x	x	x	.
All Abies grandis h.t.s	x	.	.	.	.	.	.
Thuja plicata/Clintonia uniflora	x	.	.	.	.	.	.
Tsuga heterophylla/Clintonia uniflora	x	.	.	.	.	.	.
Abies lasiocarpa/Clintonia uniflora	x	x	.	.	.	.	.
Abies lasiocarpa/Galium triflorum	.	x	x	x	.	x	.
Abies lasiocarpa/Calamagrostis canadensis	.	.	.	.	x	x	.
Abies lasiocarpa/Linnaea borealis	x	x	x	x	x	x	.
Abies lasiocarpa/Menziesia ferruginea	x	x	x	.	.	.	.
All Tsuga mertensiana h.t.s	x	.	.	.	.	.	.
Abies lasiocarpa/Xerophyllum tenax	x	x	x	.	.	.	.
Abies lasiocarpa/Vaccinium globulare	.	.	.	x	.	x	.
Abies lasiocarpa/Vaccinium scoparium	.	.	.	x	x	x	.
Abies lasiocarpa/Arnica cordifolia	.	.	.	x	x	.	.
Abies las.-Pinus albic./Vaccinium scop.	.	.	x	x	x	x	.
Abies lasiocarpa/Luzula hitchcockii	x	x	x	.	.	.	.
Pinus albicaulis-Abies lasiocarpa	x	x	x	x	x	x	.
Larix lyallii-Abies lasiocarpa	x	x	.	.	.	.	.
Pinus contorta community types	.	.	.	x	x	x	.

Table 3.--*Distribution of selected trees and undergrowth indicator plants by forest region across Montana. Northern Idaho data from Daubenmire and Daubenmire (1968)*

x = common
r = rare or scarce
. = absent

Species	Northern Idaho	Forest region NW	WC	NC	C	WC	SC	
Coastal species								
Adiantum pedatum	x	r	.	.	.	.	.	.
Asarum caudatum	x	r	.	.	.	.	.	.
Tsuga heterophylla	x	x	.	.	.	.	.	.
Tsuga mertensiana	x	x	.	.	.	.	.	.
Thuja plicata	x	x	r	.	.	.	.	.
Pinus monticola	x	x	r	.	.	.	.	.
Taxus brevifolia	x	x	r	.	.	.	.	.
Abies grandis	x	x	x-r	.	.	.	.	.
Clintonia uniflora	x	x	x-r	r	.	.	.	.
Intermountain species								
Larix occidentalis	x	x	x	.	.	.	.	.
Larix lyallii	x	x	x	x	.	.	.	.
Pinus ponderosa var.-ponderosa[1]	x	x	x	.	.	.	.	.
Xerophyllum tenax	x	x	x	x	r	r	r	.
Menziesia ferruginea	x	x	x	x	r	r	r	.
Luzula hitchcockii	x	x	x	x	r	r	r	.
Widespread species								
Widespread Rocky Mt. trees[2]	x	x	x	x	x	x	x	
Calamagrostis rubescens	x	x	x	x	x	x	x	.
Carex geyeri	x	x	x	x	x	x	x	.
Physocarpus malvaceus	x	x	x	r	x	r	x	.
Eastside species								
Pinus flexilis	.	.	r	x	x	x	x	.
Senecio streptanthefolius	.	.	.	r	x	x	x	.
Frasera speciosa	.	.	.	r	x	x	x	.
Geranium richardsonii	.	.	.	x	x	r	x	.
Pinus ponderosa var. scopulorum[3]	.	.	.	.	x	.	r	r
Juniperus horizontalis	.	.	.	x	x	r	x	x
Fraxinus pennsylvanica	.	.	.	.	.	.	.	r

[1] (Little 1953), having three-needle fascicles only.
[2] Pseudotsuga, Abies lasiocarpa, Picea, Pinus contorta, and Pinus albicaulis.
[3] (Booth 1950 and Little 1953), having many two-needle fascicles.

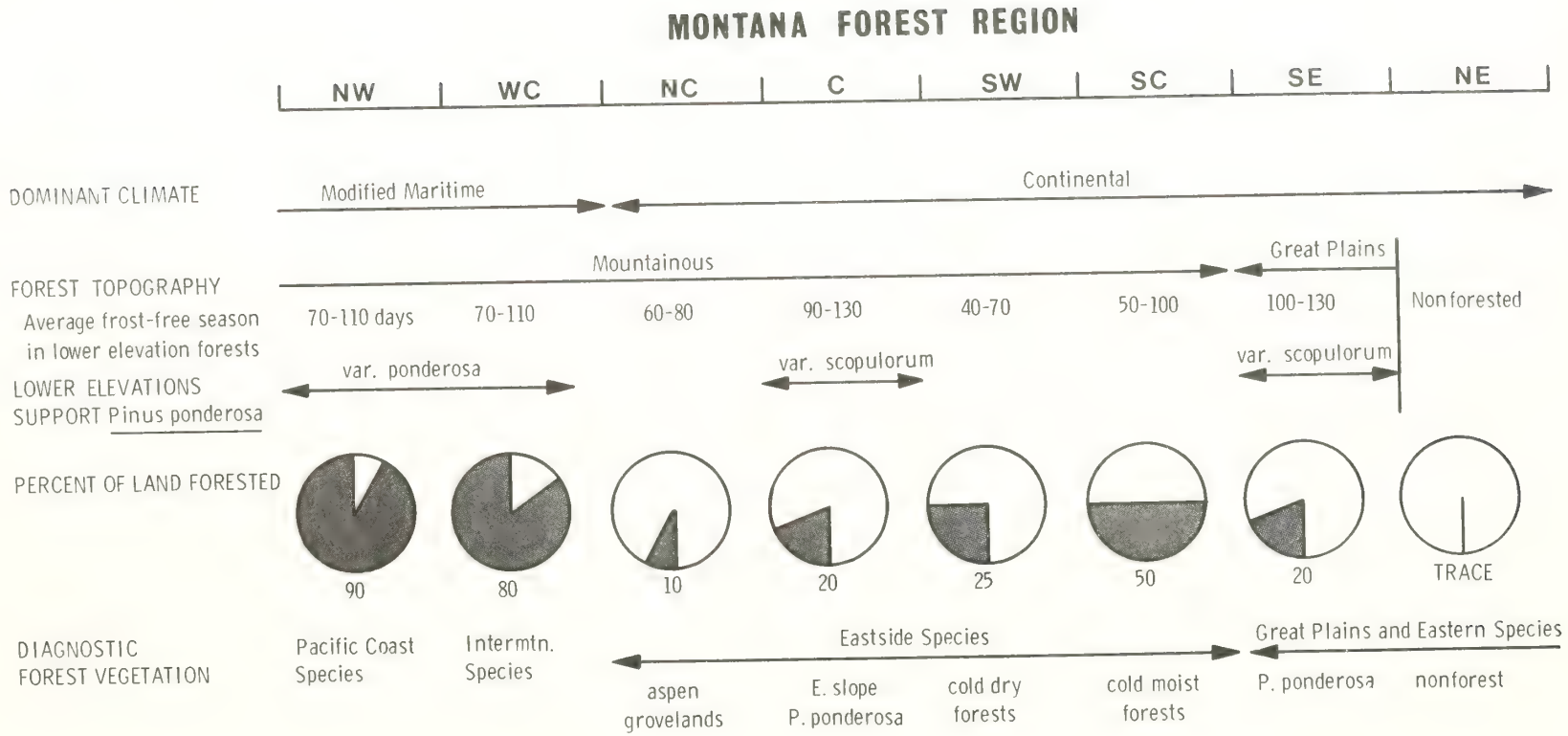

Figure 2.--Summary of the major characteristics of Montana's forest regions. (Average frost-free season, for sites with good air circulation, as interpreted from Caprio 1965.)

FOREST REGION DESCRIPTIONS

Northwestern Montana Forest Region

The northwestern forest region of Montana includes the Kootenai, Flathead, and lower Clark Fork River (as far upstream as Fish Creek and Ninemile Valley) drainages. This region is bounded on the east by the Continental Divide, on the north by British Columbia, and on the west and southwest by Idaho and the crest of the Bitterroot Mountains. The southeastern border of the region is marked by the Rattlesnake Creek and Blackfoot River divides.

Diagnostic forest vegetation

The northwest forest region has an abundance (in all but the drier valleys) of Pacific Coast forest species that are less common or absent elsewhere. Tree species largely restricted to this region include *Tsuga heterophylla*, *T. mertensiana*, *Thuja plicata*, *Abies grandis*, *Taxus brevifolia*, and *Pinus monticola*. Undergrowth largely restricted to this region includes *Clintonia uniflora*, *Aralia nudicaulis*, *Gymnocarpium dryopteris* (and other Pacific Coast ferns), *Disporum hookeri*, *Tiarella trifoliata*, *Viola glabella*, and *Oplopanax horridum* (nomenclature is from Hitchcock and Cronquist 1976).

Forest distribution

As is the case in other mountainous sections of Montana, the rugged terrain creates an array of habitats and accompanying vegetation, from semiarid grasslands in the rain shadow of large mountain masses to moist mountain valleys, subalpine forests, and alpine tundra. The generalized distribution of forest trees and climax series for an area in the Kootenai River drainage is depicted in figure 3. Major forest habitat types for northwestern Montana are listed in table 2.

About 90 percent of the land in this region is potentially forested (Hutchison and Kemp 1952; Green and Setzer 1974). Throughout much of the region, forest covers even the lowest elevation valleys (as low as 1,800 feet); in the driest valleys southwest of Flathead Lake, grassland prevails below about 3,500 feet elevation. Forest extends over all but the highest peaks (and rockiest sites). The average elevation of alpine tree line is about 8,000 feet.

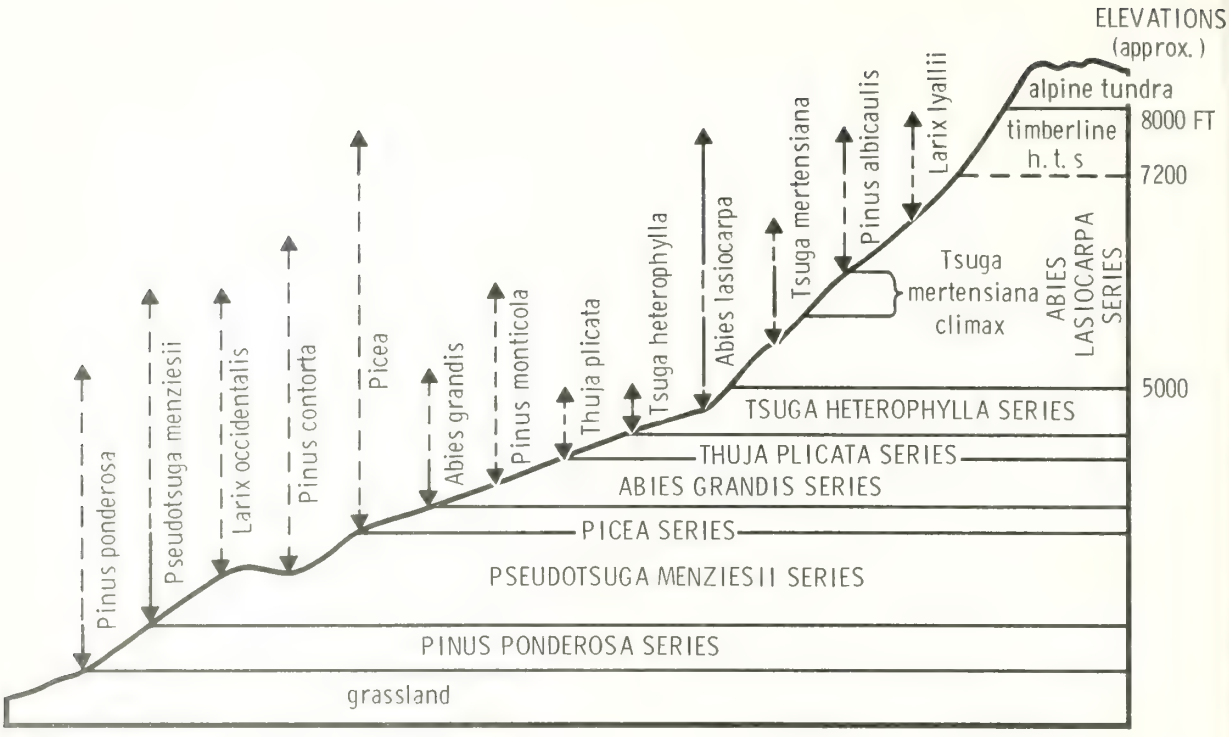

Figure 3.--Distribution of forest trees in an area of the Kootenai drainage in northwestern Montana. Arrows show the relative elevational range of each species; solid portion of the arrow indicates where species is potential climax, dashed portion shows where it is seral. (Modified from Pfister and others 1977.)

Climatic influences

Northwestern Montana is strongly influenced by moist maritime airmasses that typically funnel through this area on their way inland from the Pacific Coast (U.S. Department of Commerce 1971; Daubenmire 1969). The airmasses provide abundant rain and snowfalls and generally humid, cloudy conditions except in midsummer. The airmasses also bring the relatively mild winter temperatures (even at high elevations) that are necessary for the survival of many of the coastal forest species.

The mildest conditions are generally associated with the Kootenai drainage in the western part of the region. In the Kootenai drainage, forests most nearly resemble those of adjacent northern Idaho, representing a still moister and milder coastal climate. *Pinus monticola* is abundant and is generally the tallest and fastest growing tree in northern Idaho. However, eastward through northwestern Montana, *Larix occidentalis* assumes this role (attaining heights of 150 to 170 feet on favorable sites).

Farther east, in the upper Flathead Valley, outbreaks of arctic air occur more frequently in the winter (U.S. Department of Commerce 1971). As a result, *Tsuga heterophylla* and *Thuja* sustain frost damage and become restricted to special sites. These sites either have a climate that is moderated by the presence of a large lake (Flathead Lake and Lake McDonald) or represent sheltered "cove" forests in ravines above the valley bottom frost zones. Still, even in the upper Flathead Valley, tree and undergrowth flora reflect a Pacific influence extending all the way to the Continental Divide itself.

Weather records for Libby and Trout Creek (table 4) represent the milder, western part of this region; whereas the Polebridge station lies in the colder, upper Flathead

Table 4.--*Weather station*

Region and station	Estimated climax series	Elev.	Mean annu. precip.	Mean Max
Northwestern				
1. Libby [illegible]	PSML	[illegible]	79	19
2. Trout Creek [illegible]	ABGR	[illegible]	[illegible]	[illegible]
3. Polebridge	PICEA	[illegible]	[illegible]	[illegible]
West-central				
1. Darby [illegible]	[illegible]	3,815	[illegible]	[illegible]
2. Greenough	[illegible]	[illegible]	[illegible]	18 6.1
North-central				
1. Babb [illegible]	POTR-PIM	4,300	19	[illegible] 20
2. Blackleaf [illegible]	PIEL	4,600	21 60	[illegible] 8.5
Central				
1. Helena	near PIPO	[illegible]	19 [illegible]	111 11 5.7
2. Lewistown	PIPO	4,130	[illegible] [illegible]	107 17
Southwestern				
1. Lakeview	PSME	6,710	[illegible]	[illegible] 142
South-central				
1. Tower Falls dry edg of Yellowstone N.P.	PSME	[illegible]	[illegible]	[illegible] 16
2. Mystic Lake	PICO-ABLA	[illegible]	[illegible] 64	[illegible] 24 140
3. W. Yellowstone	PICO-ABLA	6,[illegible]	12 [illegible]	[illegible] 21 7.0
Southeastern				
1. Lame Deer	PIPO	[illegible]	[illegible] 70	≈105 [illegible] 8.2
2. Roundup	PIPO	[illegible]	24 72	129 11 6.5
Northeastern				
1. Glasgow	no forest	1,277	11 [illegible]	[illegible] [illegible]

Valley. Average annual precipitation in most of the subalpine forests of this region ranges from about 40 to 65 inches.[2]

West-Central Montana Forest Region

The west-central forest region includes the Clark Fork River drainage from the Missoula-Frenchtown Valley upstream, except for the Continental Divide range from Nevada Peak (northwest of Helena) to California Pass (south of Anaconda). This region is bounded on the west by the lofty Bitterroot Range. The Bitterroot Range forms the Montana-Idaho Divide and constitutes a significant barrier to Pacific Coast moisture and thus to coastal plants.

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[2] These estimates were based on U.S. Dep. Comm. (1971), U.S. Dep. Comm. weather station data, USDA Soil Conserv. Serv. (1968), Arno (1970), and an isohyetal analysis for the Columbia River drainage prepared by the U.S. Weather Bureau River Forecast Center, Portland, Oregon, in 1968.

Diagnostic forest vegetation

Although it has a relatively mild, Pacific-influenced climate, this region's fo ests are generally drier than those of either northwestern Montana or adjacent north Idaho. Thus, the region has only small amounts of Pacific Coast forest species such *Thuja plicata, Pinus monticola, Taxus brevifolia, Clintonia uniflora, Adenocaulon bi color, Coptis* spp. (of western North America), and *Tiarella trifoliata.* These speci are restricted to moist canyon-bottom sites or seepage areas and generally reach the southeastern limits within this region (table 3). *Abies grandis* is locally common, is much less abundant than it is in northwestern Montana. West-central Montana is c acterized by an abundance of the intermountain forest species--*Larix occidentalis, L lyallii, Pinus ponderosa* var. *ponderosa, Xerophyllum tenax, Menziesia ferruginea,* an *Luzula hitchcockii.* These species become rare or absent in the remaining regions th lie farther east (table 3).

Forest distribution

As figure 4 shows, the typical array of forest series here is not as diverse as that in northwestern Montana, because of the scarcity of Pacific Coast species. Abo

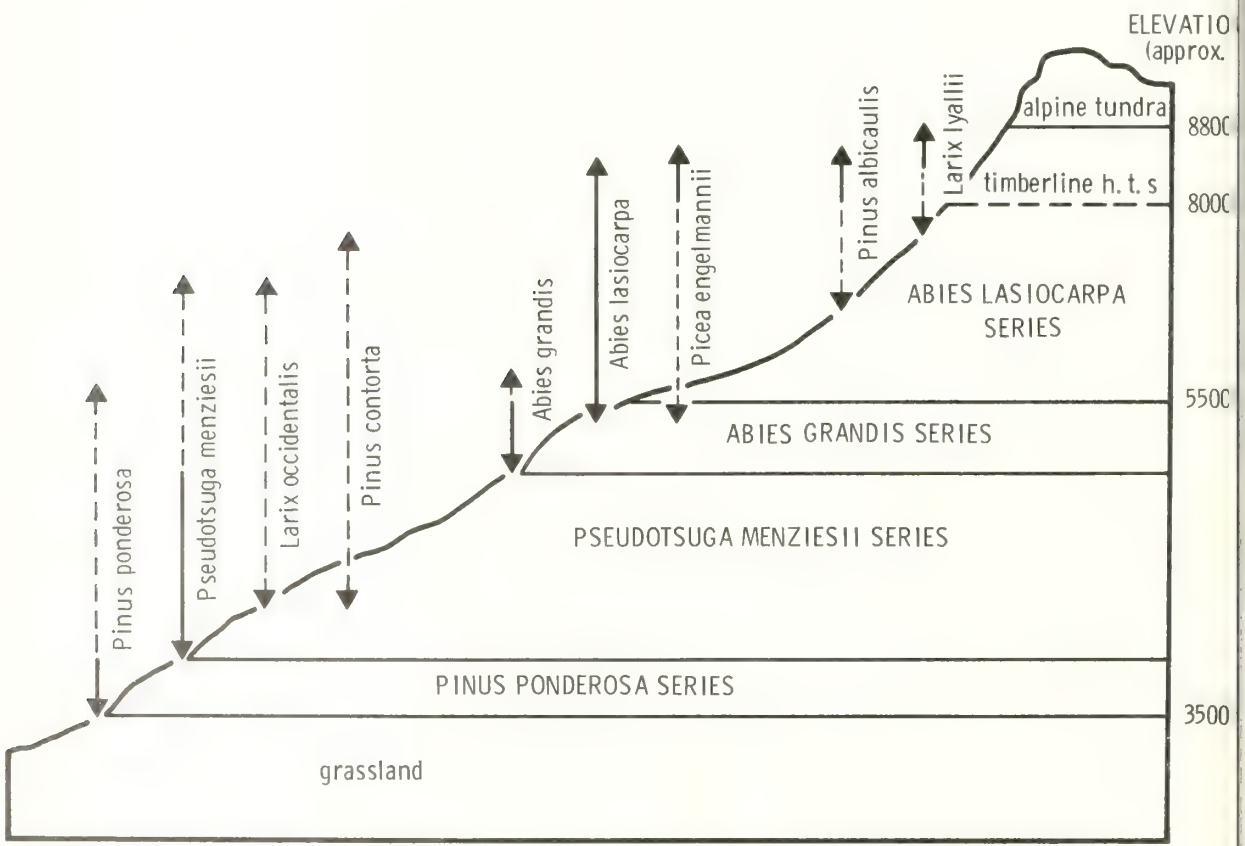


Figure 4.--Distribution of forest trees in an area of west-central Montana. Arrow show the relative elevational range of each species; solid portion of the arrow indicates where a species is the potential climax and dashed portion shows where it is seral. (Modified from Pfister and others 1977).

0 percent of the land in this region is potentially forested. [illegible]
and is grassland [illegible]
of Mueggler and Handl (In press) that occur in the [illegible]
annual precipitation on these nonforest valley sites is [illegible]
are well-drained. However, this grassland is not extensive, [illegible]
generally occurs within 1,000 feet of the valley base elevation, [illegible]
between about 3,200 and 5,500 feet. Forest extends over all but the highest peaks
(and rockiest sites). The average elevation of alpine tree line is about 8,800 feet.
Principal forest habitat types of west-central Montana are shown in table 2.

Climatic influences

The comparatively dry, Pacific-influenced climate of this region is illustrated by data from the locations of Darby and Greenough (table 4). Average annual precipitation in the subalpine forests is generally 35 to 55 inches (footnote 2).

Seral *Pinus ponderosa* and *Larix occidentalis* form the largest and most commercially important west-central Montana forest trees; they often attain heights of 130 to 140 feet at maturity. The exception is the southeastern part of this region where valley base elevations are high and forests are dominated by *Pinus contorta*. (However, the intermountain undergrowth species dominate.)

North-Central Montana Forest Region

The north-central Montana forest region includes all the forested terrain along the east slope of the Continental Divide from the drainage of the North Fork of the Dearborn River north to the Canadian border and east to Havre. Adjacent southern Alberta has similar forest environments.

Diagnostic forest vegetation

This area supports the most extensive *Populus tremuloides* groves in the State (Lynch 1955) as well as large patches of *Pinus flexilis* woodland along the lower skirts of the mountains. *Pinus ponderosa* is absent, apparently because of the excessively cold and windy winter conditions. A narrow band of *Abies lasiocarpa* (series) forest along the Rocky Mountain front supports the easternmost occurrences of intermountain undergrowth species, *Menziesia ferruginea*, *Xerophyllum tenax*, *Luzula hitchcockii*, and even "cove sites" with *Clintonia uniflora* barely extending across the Divide from northwestern Montana (appendixes A-7, -8, and -10); however, the limited tree flora and its stunted growth are definitely indicative of the severe eastside climatic conditions.

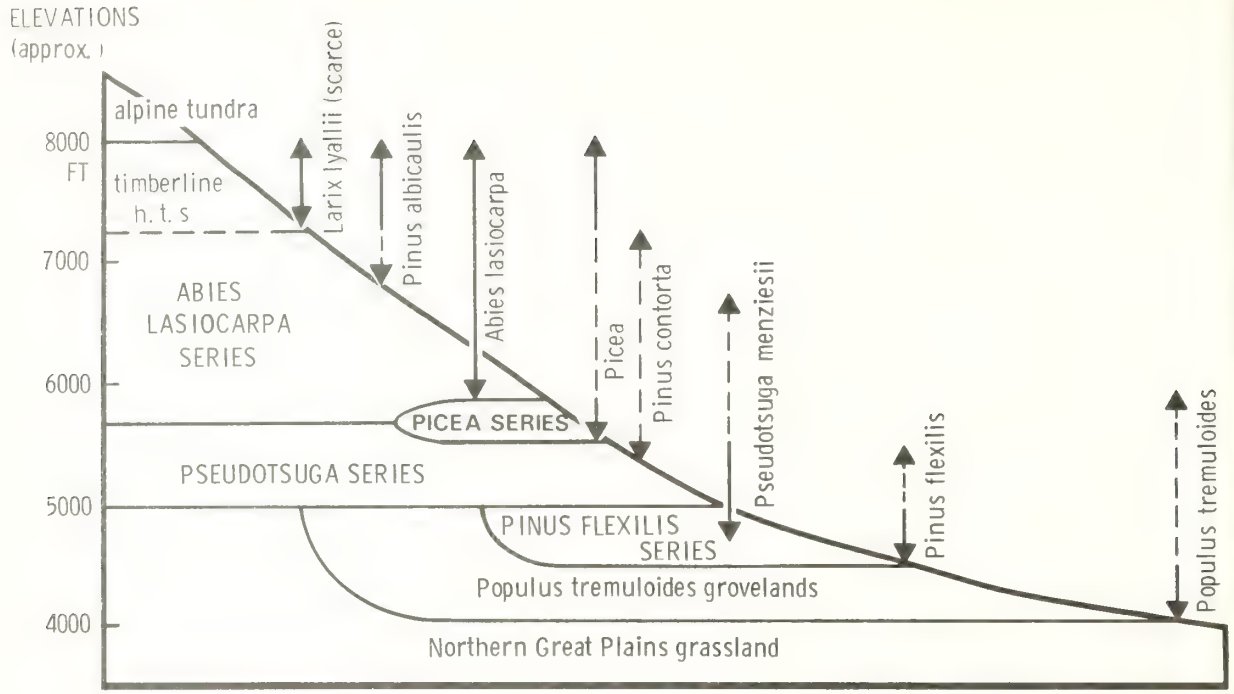


Figure 5.--Distribution of forest trees in an area of north-central Montana. Arrows show the relative elevational range of each species; solid portion of the arrow indicates where a species is the potential climax and dashed portion shows where it is seral.

Forest distribution

Only about 10 percent of the land in this region is potentially forested, most of it occurring in a 20 to 30 mile band along the eastern skirts of the Continental Divide or Front Range of the Rockies. Figure 5 illustrates a characteristic distribution of tree species in this region. A small area of similar forest (8 mi^2), lacking only *Larix lyallii*, occurs on the Sweetgrass Hills (elev. 6,983 feet) 90 miles east of the nearest Front Range stands (Thompson and Kuijt 1976).

Lower timberline generally occurs between 4,500 and 5,000 feet and forest extends up to all but the highest ridges and peaks. Alpine tree line averages about 8,000 feet. Most of the nonforest land is potentially grassland dominated by *Agropyron*, *Festuca*, *Bouteloua*, and *Stipa* (Kuchler 1964; Mueggler and Handl, In press).

Climatic influences

North-central Montana has a continental climate with severe chinook winds and dramatic fluctuations of winter temperatures that often injure forest trees. On wind-exposed slopes, tree growth is stunted by "red belt" conditions. Branches, groups of trees, or even sizable stands are routinely killed by desiccation of foliage caused when warm, dry chinook winds occur while the ground is frozen and little water is available to replace transpiration losses. *Pinus flexilis* (at low and middle elevations) and *P. albicaulis* (at high elevations) are least susceptible to red belt damage.

Growing seasons are short and cool in the lower elevation forest sites (table 4 nd figure 2). Except in protected valleys, trees seldom reach 70 feet in height. verage annual precipitation in the subalpine forests is generally 30 to 40 inches footnote 2), although it is much greater in a few areas along the Continental Divide, articularly in Glacier National Park. The severity of winter temperature fluctuations s illustrated by the world-record temperature drop of 100° F in 24 hours (from +44° to 56°F) at Browning, near East Glacier Park, in January 1916 (McWhirter and McWhirter 972).

Central Montana Forest Region

The central Montana forest region includes all the forested terrain from the Helena Valley east to Harlowton, Lewistown, and Fort Peck Reservoir, and north to Havre. Specifically, the western edge runs along the Continental Divide from the drainage of the Middle Fork of the Dearborn River south to the Boulder River divide. Forests contiguous with and west of the divide are included from the Avon Valley south to Deer Lodge (from Nevada Peak to Electric Peak along the Continental Divide). Eastward, the area encompasses the Elkhorn Mountains (except for the southwestern portion of that range that drains into the Boulder River) as well as the Big Belt, Little Belt, Castle, Big Snowy, Little Snowy, Judith, Little Rocky, Bearpaw, and Highwood Mountains. The range also contains rather extensive lowland *Pinus ponderosa* (var. *scopulorum*, Booth 1950, Little 1953) forests in the Helena and Lewistown vicinities and in the Missouri River Breaks.

Diagnostic forest vegetation

Most of central Montana has a low-elevation forest belt of *Pinus ponderosa* (var. *scopulorum*). In contrast to westside *P. ponderosa* (var. *ponderosa*), these have many two-needle fascicles and a short growth form. Additionally, central Montana has mountain forests made up of other climax series (table 1). The other eastside region containing *P. ponderosa* (southeastern Montana) does not have additional forest series.

Coastal and intermountain species are essentially absent, while eastside species, including *Pinus flexilis* and *Juniperus horizontalis*, are prominent (table 3). Great Plains grassland elements such as *Bouteloua gracilis* and *B. curtipendula*, *Yucca glauca*, and *Opuntia fragilis*, and *O. polyacantha* are commonly found in the driest *Pinus ponderosa* and *P. flexilis* stands.

Forest distribution

Approximately 20 percent of the land in this region is potentially forested. Most of the nonforest land is potentially grassland dominated by *Agropyron*, *Festuca*, *Bouteloua*, and *Stipa* (Kuchler 1964; Mueggler and Handl, In press). The forests are associated with prominent mountain ranges and the Missouri River Breaks. Forest extends from valley base levels or from lower timberlines on the principal mountain ranges (at 4,000 to 5,500 feet) and covers all but the highest peaks. Alpine tree line averages about 8,500 feet. Figure 6 shows a characteristic distribution of tree species on non-limestone parent materials in central Montana.

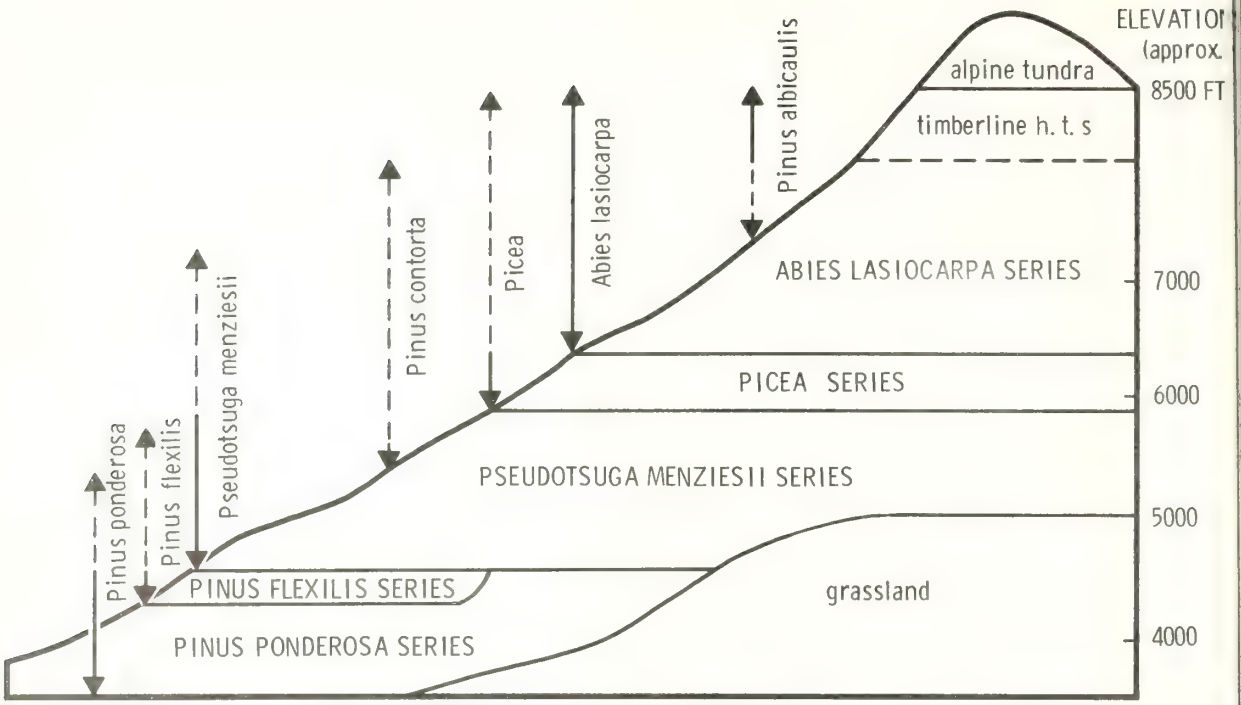


Figure 6.--Distribution of forest trees in an area of central Montana. Arrows show t relative elevational range of each species; solid portion of the arrow indicates wh a species is the potential climax and dashed portion shows where it is seral.

Extensive areas having limestone substrates occur in the mountain ranges of cent Montana. The limestone-derived soils drain rapidly and are generally dominated by drier site species than the adjacent nonlimestone sites (fig. 53, 54, in Pfister and others 1977). For example, at medium elevations the limestone sites often support *Pseudotsuga* with a grass-forb undergrowth, while adjacent granitic sites have *Pinus contorta* and *Vaccinium* spp. (Goldin and Nimlos 1977; Weaver and Parry 1978).

Climatic influences

This region has a continental climate, but has forests extending to lower elevations and less severe winter conditions than north-central Montana. The warmer July temperatures and longer growing seasons (fig. 2) in the lower forest zone are indicated by weather station data in table 4. However, except on sheltered sites, trees seldom attain 80 feet in height. Average annual precipitation in the subalpine forests is estimated to be 25 to 35 inches (footnote 2).

In the higher valleys and at high elevations in the mountains, extreme temperatu changes accompanied by strong winds inflict red belt damage. For instance, in mid-January 1971 such weather conditions (temperatures fluctuating between -30° and +58° at Great Falls, accompanied by strong winds) killed about 20,000 acres of *Pinus conto* forest in the Little Belt Mountains.

Southwestern Montana Forest Region

Area included

The southwestern Montana forest region includes the Jefferson, Madison, and Boulder River drainages, east of the Continental Divide, as well as the forests on both slopes of the Continental Divide range in the vicinity of Butte (specifically from Electric Peak, east of Deer Lodge, to California Pass, south of Anaconda).

As in central Montana, Pacific Coast forest elements are absent and intermountain elements are scarce (table 3). Rather short, but stout *Pseudotsuga* (or *Pinus flexilis*) occupy the warmest forest sites, and *Pinus contorta* along with *Vaccinium scoparium* undergrowth dominate most high-elevation forests. Undergrowth is notably sparse in the denser forest stands, and in *Pseudotsuga* forests undergrowth often consists primarily of scattered *Festuca idahoensis* and even *Artemisia tridentata*. Figure 7 shows a characteristic distribution of tree species in southwestern Montana. Principal forest habitat types are shown in table 2.

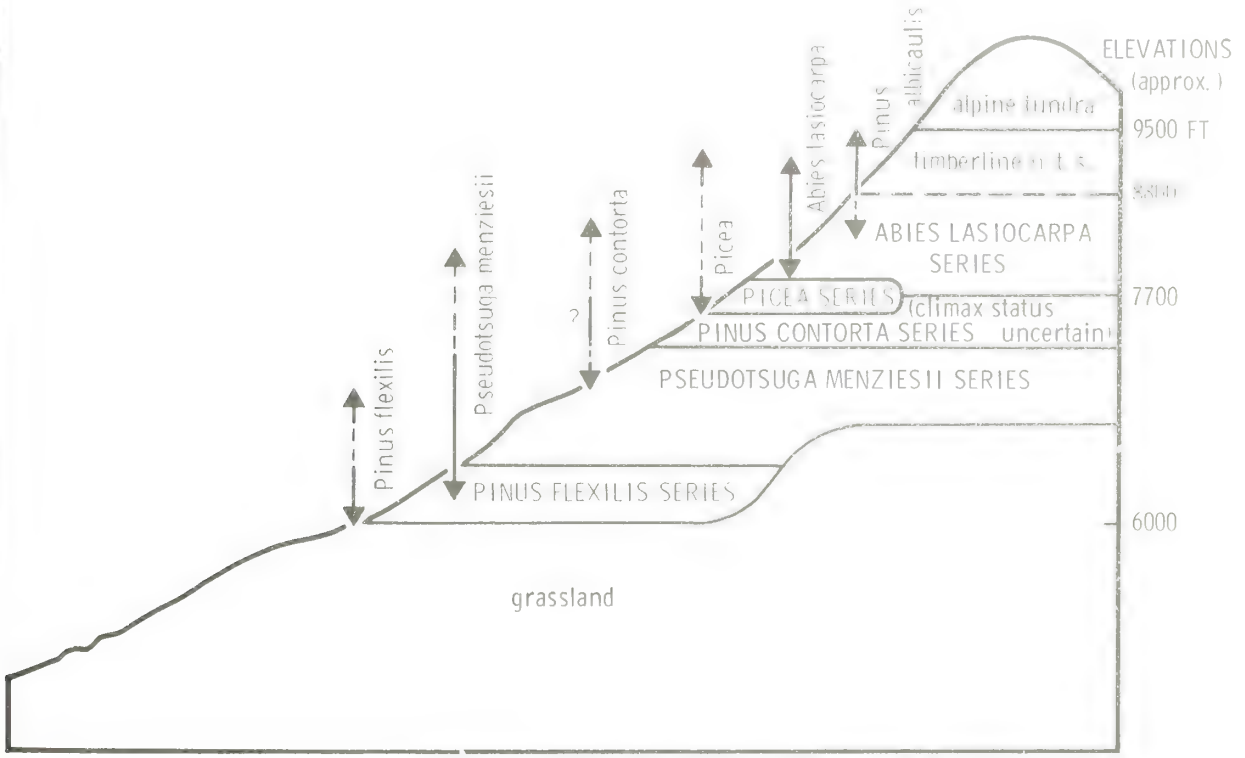


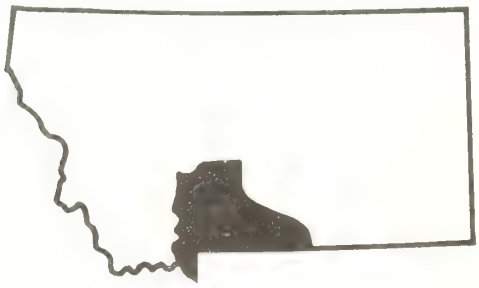
Figure 7.--Distribution of forest trees in an area of southwestern Montana. Arrows show the relative elevational range of each species; solid portion of the arrow indicates where a species is the potential climax and dashed portion shows where it is seral.

Forest distribution

Despite its mountainous terrain, only about one-fourth of this region is forested Most of the nonforest land is semiarid steppe (*Artemisia*) and grassland (*Agropyron, Festuca,* and *Stipa*), along with small areas of alpine vegetation (Kuchler 1964; Mueggl and Handl, In press) above 9,500 feet elevation. Lower timberline generally occurs somewhere between 5,700 and 7,000 feet in elevation. However, some of the mountain ranges south of Dillon are so dry that little forest is supported even at 8,000 feet. Thus, the entire forest belt (between lower and upper timberline) may span only 1,000 to 1,500 feet of elevation, and may be locally absent on exposed south- and west-facin slopes. Similarly high, semiarid mountain ranges, projecting above an *Artemisia tridentata* steppe (Kuchler 1964), occur in adjacent east-central Idaho (Steele and others (footnote 1)).

Climatic influences

As illustrated by weather records from Lakeview (table 4), this is a cold, dry forest region having high valley-base elevations, and a continental climate. Average annual precipitation in the subalpine forest ranges from about 22 to 35 inches (footnote 2). This forest region evidently has growing seasons too short and cold for *Pinus ponderosa* (fig. 2). The cold, dry conditions are also evidenced by the lack of *Pseudotsuga/Physocarpus* habitat type (tables 2 and 3). However, chinook winds and temperature fluctuations are less severe than in north-central and central Montana, and red belt damage is less common.



South-Central Montana Forest Region

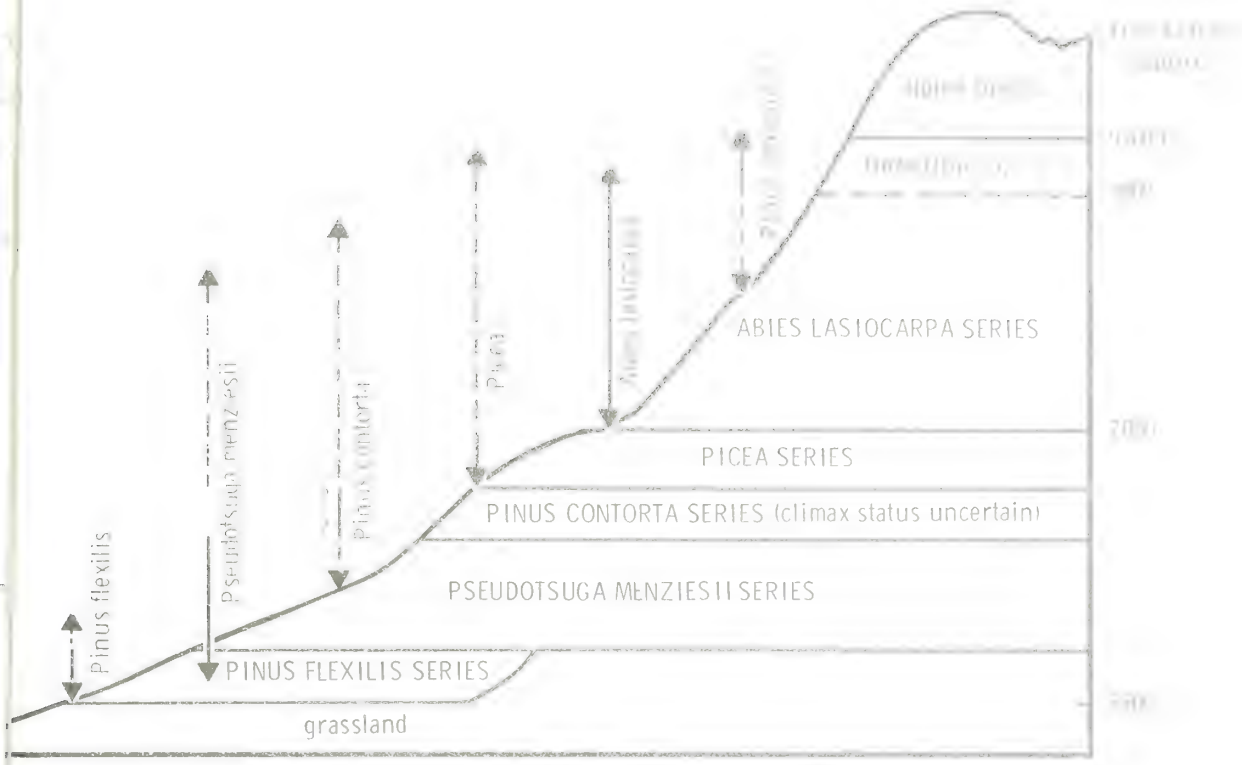
The south-central Montana forest region includes the Gallatin and upper Yellowsto River drainages (along with the Bridger and Crazy Mountains) as well as the Pryor Mountains and the north end of the Bighorn Range. The region encompasses the northern par of an extensive, high-elevation forested upland surrounding Yellowstone National Park. This upland is capped by large alpine plateaus in Montana and Wyoming.

Diagnostic forest vegetation

Most of the forest in south-central Montana is dominated by *Pseudotsuga, Pinus contorta, Picea,* or *Abies lasiocarpa*. The abundance of *Picea/Physocarpus, Picea/Galium triflorum, Abies lasiocarpa/Galium triflorum,* and *Abies lasiocarpa/Calamagrostis canadensis* habitat types (table 2) attests to the moistness of many of the forests. Also, scattered populations of *Xerophyllum* and *Menziesia* (appendixes A-9 and -10) are found here, more than 100 miles east of their usual distributional limits near the Continent Divide. In contrast to southwest Montana, one seldom finds extensive stands having a grassland undergrowth (except on limestone substrates), nor does one find very sparse undergrowth related to dry conditions.

Forest distribution

Nearly half of the land in south-central Montana supports forest, and most of the remaining area is potentially grassland--(*Agropyron, Festuca, Stipa*) according to



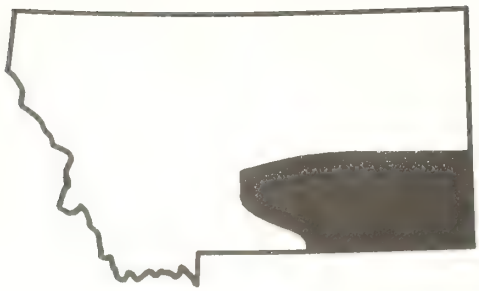
igure 8.--Distribution of forest trees in an area of south-central Montana. Arrows show the relative elevational range of each species; solid portion of the arrow indicates where a species is the potential climax and dashed portion shows where it is seral. (Modified from Pfister and others 1977.)

uchler (1964)--occupying the drier, lower elevation valleys. Lower timberline averages about 5,500 feet and alpine tree line occurs near 9,500 feet. Figure 8 shows a haracteristic distribution of tree species in an area of south-central Montana. Table lists principal forest habitat types.

Limestone substrates are abundant in the Pryor Mountains and occur sporadically lsewhere in south-central Montana. These sites, below about an 8,000-foot elevation, enerally have forests dominated by *Pinus flexilis* and *Pseudotsuga*.

limatic influences

South-central Montana has a continental climate, and red belt injury is often severe at lower timberline. The valleys have high base elevations and are too cold short growing season, figure 2) for any significant amounts of *Pinus ponderosa*; however, forests are generally moister than those of southwestern Montana. Weather records for three forested sites in this region are found in table 4. Average annual precipitation in the subalpine forests is generally 30 to 45 inches (footnote 2).



Southeastern Montana Forest Region

The southeastern Montana forest region includes the extensive pure *Pinus ponderosa* forests on lowlands and hilly terrain (mostly 2,800 to 4,400 feet elevation) in the northern Great Plains. It covers the lower Yellowstone River drainage as far upstream (west) as Big Timber. The region extends up the Musselshell Valley to Harlowton and its northern boundary includes the northernmost pine groves in the vicinities of Roundup, Miles City, and Baker.

Diagnostic forest vegetation

Although *Pinus ponderosa* is the only forest tree, it occurs in rather diverse habitat types (table 2). The driest of these forest sites have very open stands of short trees (35-60 feet), with grassland undergrowth (e.g., *Andropogon gerardii* and *A. scoparius*, *Agropyron spicatum*, *Bouteloua gracilis*, *Carex filifolia*). Conversely, moist north-facing slopes have dense stands of *P. ponderosa* (70-95 feet tall), with a luxuriant shrub and herb undergrowth including many species characteristic of the mountain forests to the west (e.g., *Shepherdia canadensis*, *Arctostaphylos uva-ursi*, *Berberis repens*, *Linnaea borealis*, *Arnica cordifolia*, *Disporum trachycarpum*, *Pyrola secunda*, and *Smilacina stellata*).

The presence of *Linnaea* and some other undergrowth species strongly suggests that the more moist habitats would support *Pseudotsuga*; however, the nearest seed source for this species is at least 70 miles away in the Bighorn Range. This conclusion is reinforced by the fact that *Pinus ponderosa* stands developing on the moister sites are more heavily stocked than is characteristic of *P. ponderosa* habitat types elsewhere in the State.

In addition to having a shorter growth form than its counterpart west of the Continental Divide, the *P. ponderosa* (var. *scopulorum*, Booth 1950 and Little 1953) in southeastern Montana has a majority of two-needle fascicles. These may be manifestations of substantial genetic differences between the west slope and Great Plains *P. ponderosa*.

Two eastern deciduous-forest species (*Fraxinus pennsylvanica* and *Prunus americana*) occur along streams and moist lower north slopes in southeastern Montana, and two other such species (*Ulmus americana* and *Quercus macrocarpa*) reach the eastern edge of this region (Little 1971, 1976). Pfister and others (1977) have discussed compositional similarities between the *P. ponderosa* forests of southeastern Montana and those of the Black Hills of western South Dakota as sampled by Thilenius (1972).

Forest distribution

Approximately 20 percent of southeastern Montana supports forest. This is a region without prominent mountains, or mountain forests; thus, it differs from all other forested regions. (Northeastern Montana does not have mountains, but also is without Great Plains *Pinus ponderosa* forest.)

Most of the remainder of the region is Great Plains grassland (*Bouteloua-Stipa-Agropyron*, according to Kuchler 1964). Some of this grassland has widely scattered pines, and thus can be termed a "savanna."

Southeastern Montana has a continental climate. Summers are longer, hotter, and more humid than those in the mountainous forest regions (table 4 and figure 2). Most of the annual precipitation (ranging up to about 18 inches in moist forest areas) comes in spring and summer rains. Winters are generally dry and cold, but are not as severe as those in the northern parts of Montana east of the Continental Divide.

Northeastern Montana

The northeastern part of Montana includes the area north of Miles City and east of the Missouri River Breaks. Potential natural vegetation is Great Plains grassland (*Bouteloua-Stipa-Agropyron* and *Agropyron-Stipa*, according to Kuchler 1964) except for stands of *Populus deltoides* lining the principal rivers. This region has no upland forest, except for a few widely scattered populations of stunted *Pinus ponderosa*. (The most notable stand is at the Pines Recreation Area south of Glasgow on Fort Peck Reservoir.) The extremely cold continental winters, coupled with desiccating winds, may be the factors preventing *Pinus ponderosa* from growing here. Average annual precipitation is between 11 and 15 inches in this region (U.S. Dep. Comm. 1971). Table 4 presents climatic data from Glasgow.

RESEARCH AND MANAGEMENT APPLICATIONS

The forest regions presented here were developed to describe distributions of forest habitat types (Pfister and others 1977)--i.e., forest sites and vegetation in mature stands. The regions can also be used in describing distributions of individual forest species or seral forest communities (e.g., *Acer glabrum-Salix* brushfields). The Northern Region of the USDA Forest Service recently adopted forest regions as "seed transfer zones" to help insure that nursery-raised seedlings are sent to a geographic area similar to the one where the seeds were collected.

These forest regions may be useful as a biologically based regional stratification for forest research and forest management studies. For example, it might be useful to stratify productivity estimates (site index and yield capability) of individual habitat types by forest region. Similarly, these forest regions logically could be incorporated in studies of genetic variation in tree species and in tree improvement programs.

Responses of trees and other vegetation to management are often stratified by habitat type, but it may be useful to analyze them by forest region as well. Forest regions offer an additional dimension for interpreting variation in forest vegetation. Forest managers may find appendix C useful for determining the location of forest region boundaries.

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APPENDIX A

Distribution of key tree and undergrowth species in Montana

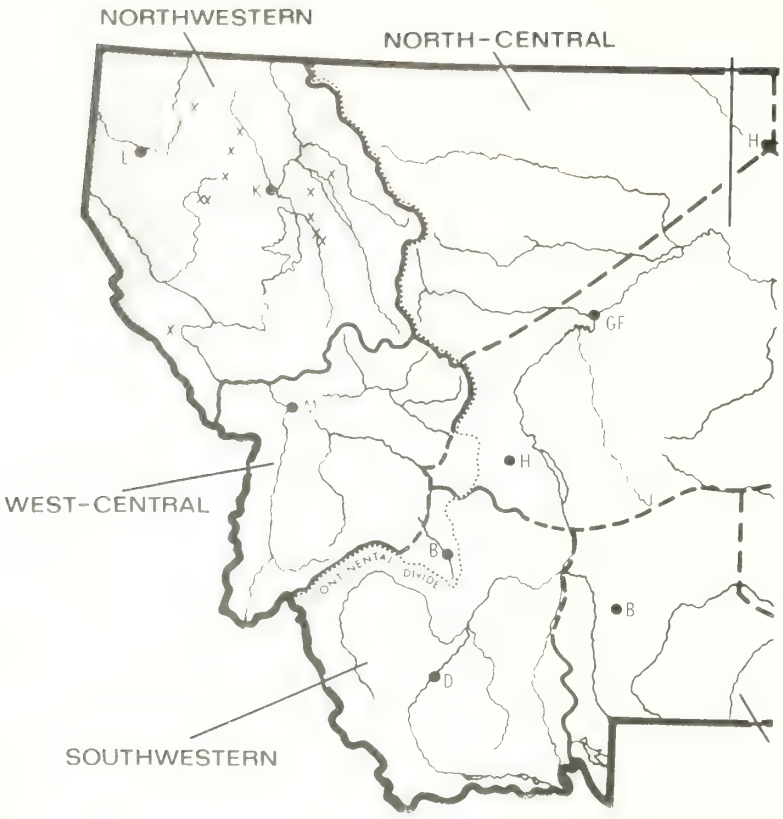

Figure A-1.--Natural distribution of Tsuga heterophylla *in Montana (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

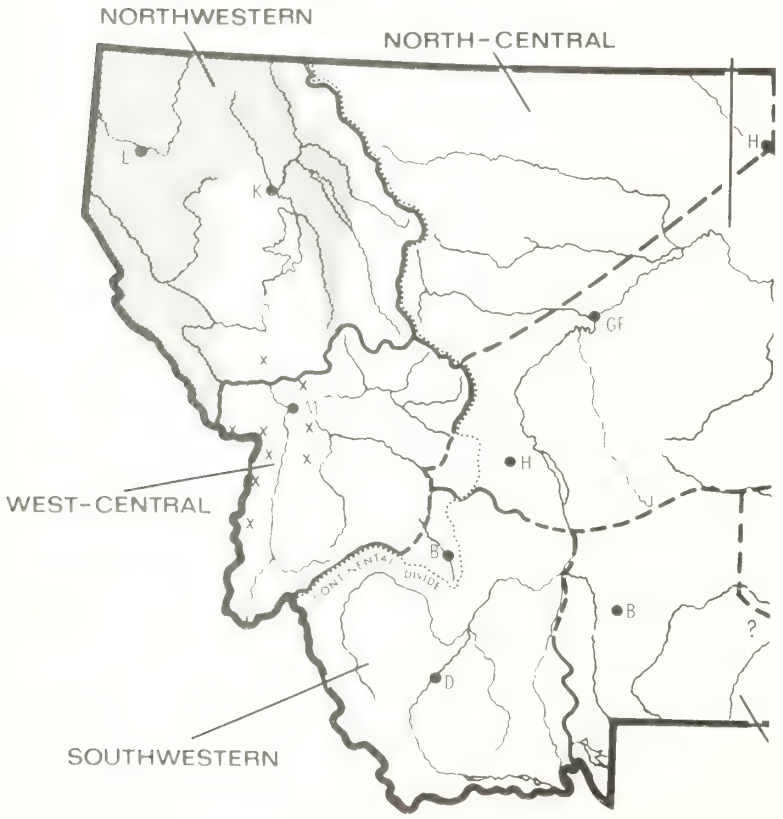

Figure A-2.--Natural distribution of Pinus monticola *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

Figure 4-3.--Natural distribution of Thuja plicata *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

Figure 4-4.--Natural distribution of Abies grandis *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

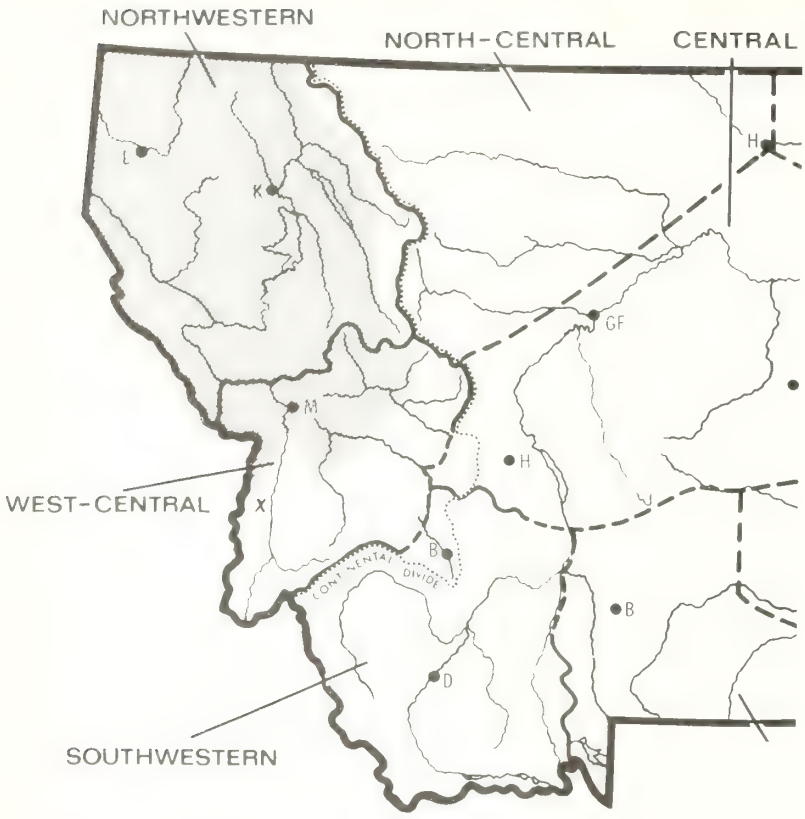

Figure A-5.--Natural distribution of Larix occidentalis *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

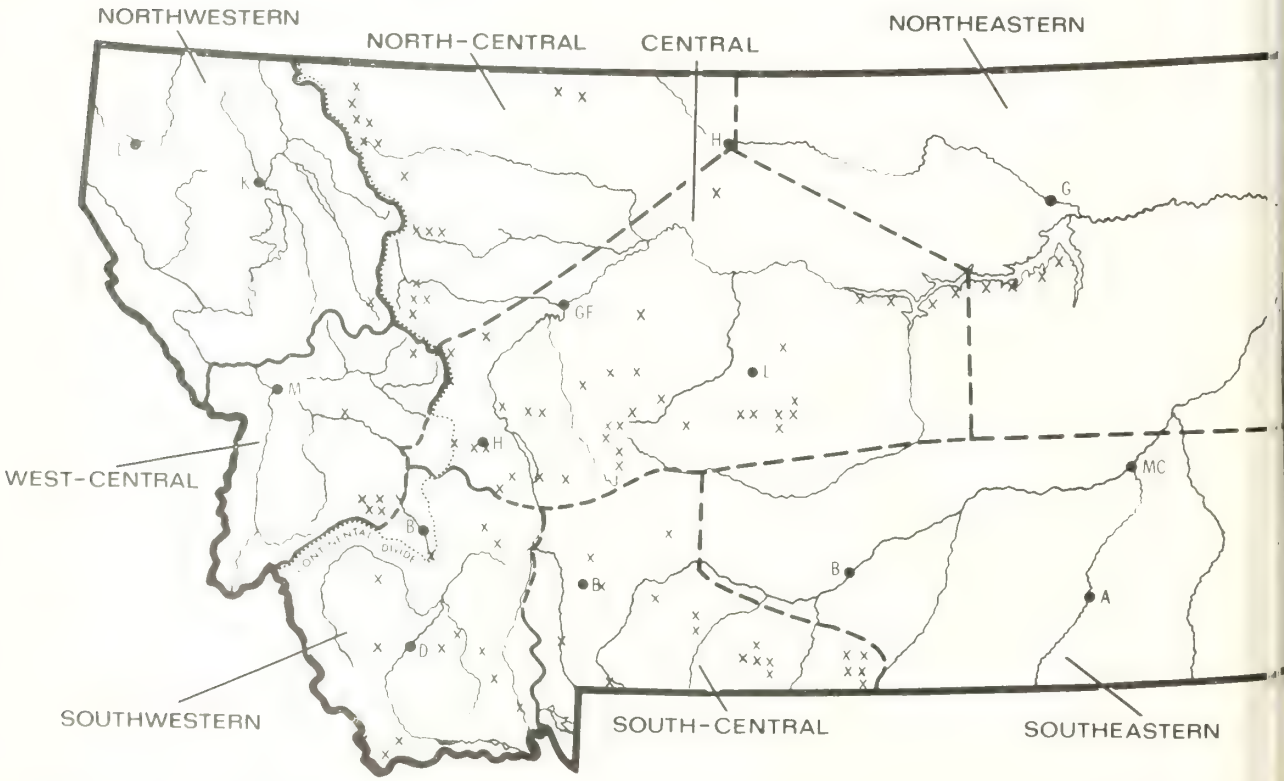

Figure A-6.--Natural distribution of Pinus flexilis *(plot locations and observations only) in Montana.*

Figure A-7.--Natural distribution of Clintonia uniflora *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

Figure A-8.--Natural distribution of Luzula hitchcockii *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

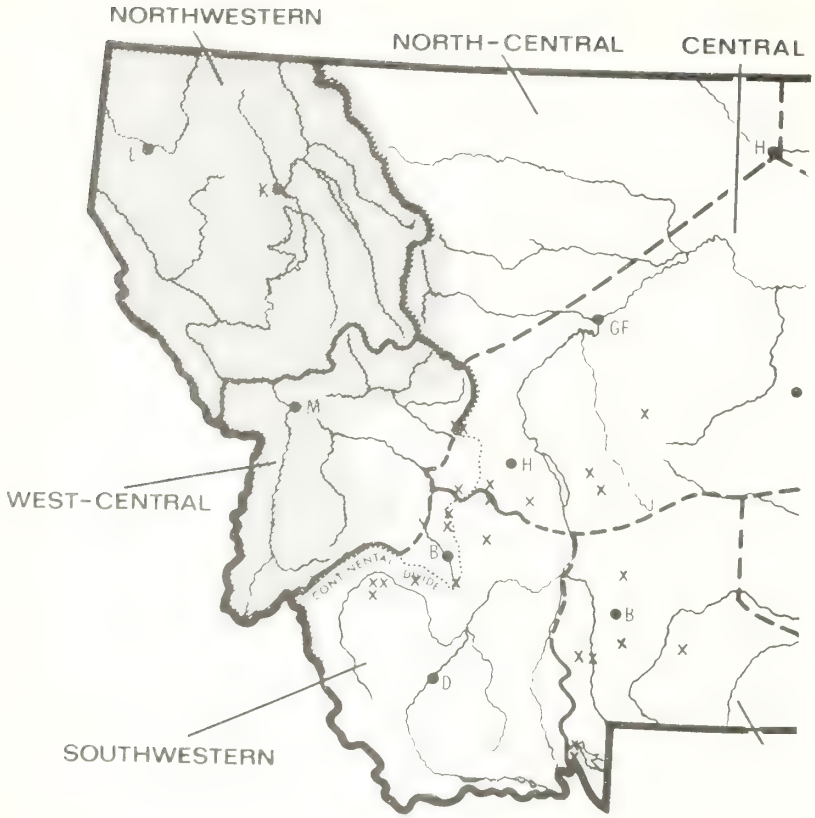

Figure A-9.--Natural distribution of Menziesia ferruginea *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

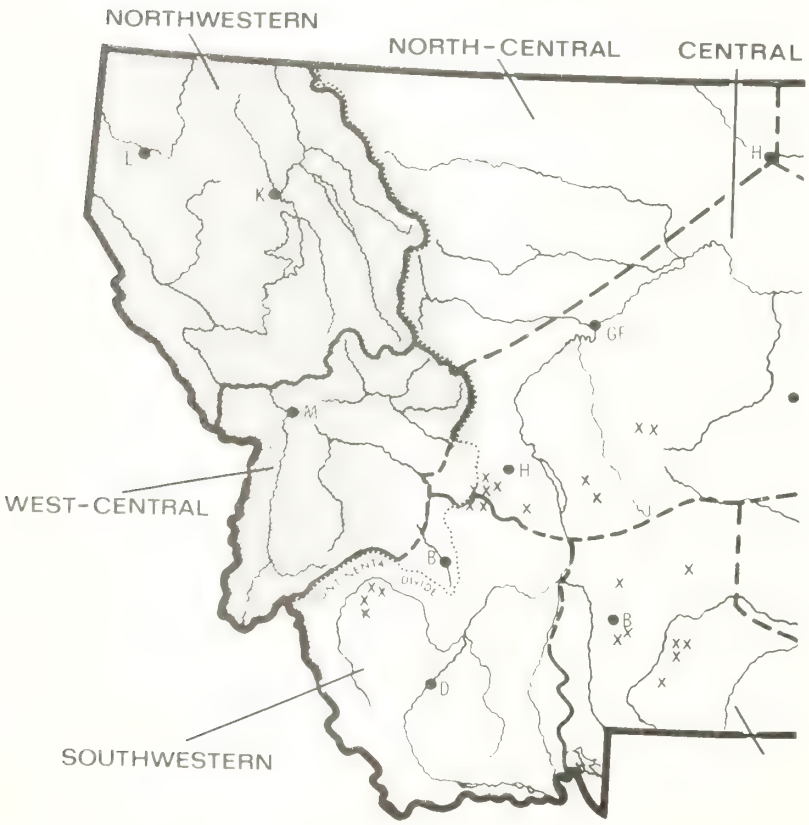

Figure A-10.--Natural distribution of Xerophyllum tenax *in Montana. (Species common in suitable habitats within shaded area. X's indicate small outlying populations.)*

APPENDIX B

Number of sample plots (Pfister and others 1977)
by habitat type, phase, and forest region in Montana

Table B-1--*Number of sample plots (Pfister and others 1977) by habitat type, phase, and forest region in Montana. (c.t. = community type)*

NW = Northwestern Montana
WC = west-central Montana
NC = north-central Montana
C = central Montana
SW = southwestern Montana
SC = south-central Montana
SE = southeastern Montana

Series/habitat type/phase	Montana forest region							
	NW	WC	NC	C	SW	SC	SE	Total
Forested scree	2	7	2	5	.	.	.	16
								16
Pinus flexilis series								
/Agropyron spicatum h.t.	.	.	1	2	2	1	.	6
/Festuca idahoensis h.t.								
-Festuca idahoensis phase	.	.	1	2	2	2	.	7
-Festuca scabrella phase	.	.	1	3	.	.	.	4
/Juniperus communis h.t.	.	.	1	1	1	4	.	7
			4	8	5	7		24
Pinus ponderosa series								
/Andropogon spp. h.t.	.	.	.	.	.	.	1	1
/Agropyron spicatum h.t.	4	7	.	2	.	.	8	21
/Festuca idahoensis h.t.								
-Festuca idahoensis phase	.	9	.	1	.	.	4	14
-Festuca scabrella phase	2	9	.	5	.	.	.	16
/Purshia tridentata h.t.								
-Agropyron spicatum phase	.	3	.	1	.	.	.	4
-Festuca idahoensis phase	3	2	.	2	.	.	.	7
/Symphoricarpos albus h.t.								
-Symphoricarpos albus phase	1	3	.	2	.	.	2	8
-Berberis repens phase	.	.	.	2	.	.	1	3
/Prunus virginiana h.t.								
-Prunus virginiana phase	.	.	.	.	.	.	6	6
-Shepherdia canadensis phase	.	.	.	.	.	.	2	2
	10	33		15			24	82
Pseudotsuga menziesii series								
/Agropyron spicatum h.t.	1	4	.	5	1	2	.	13
/Festuca idahoensis h.t.	1	1	.	.	14	3	.	19
/Festuca scabrella h.t.	5	2	.	6	.	.	.	13
/Vaccinium caespitosum h.t.	15	9	1	2	.	.	.	27
/Physocarpus malvaceus h.t.								
-Physocarpus malvaceus phase	12	23	.	3	1	6	.	45
-Calamagrostis rubescens phase	1	7	.	.	.	.	.	8

(con.)

Table B-1.--(con.)

Series/habitat type/phase	Montana forest region							
	NW	WC	NC	C	SW	SC	SE	
Pseudotsuga menziesii series								
/Vaccinium globulare h.t.								
-Vaccinium globulare phase	2	4	.	5	1	1	.	13
-Arctostaphylos uva-ursi phase	2	7	.	.	.	.	.	9
-Xerophyllum tenax phase	6	11	.	1	.	.	.	18
/Linnaea borealis h.t.								
-Symphoricarpos albus phase	3	4	.	2	.	.	.	9
-Calamagrostis rubescens phase	1	5	.	4	2	.	.	12
-Vaccinium globulare phase	.	8	.	1	.	.	.	9
/Symphoricarpos albus h.t.								
-Agropyron spicatum phase	1	6	.	2	.	.	.	9
-Calamagrostis rubescens phase	9	17	.	5	3	6	.	40
-Symphoricarpos albus phase	1	5	3	4	2	3	.	18
/Calamagrostis rubescens h.t.								
-Agropyron spicatum phase	5	5	.	.	.	.	.	10
-Arctostaphylos uva-ursi phase	2	7	.	2	.	.	.	11
-Calamagrostis rubescens phase	3	23	1	13	15	7	.	62
-Pinus ponderosa phase	3	8	.	3	.	.	.	14
/Carex geyeri h.t.	.	3	.	4	1	2	.	10
/Spiraea betulifolia h.t.	2	2	4	3	.	.	.	11
/Arctostaphylos uva-ursi h.t.	.	.	.	7	.	1	.	8
/Juniperus communis h.t.	.	.	1	6	7	.	.	14
/Arnica cordifolia h.t.	.	.	.	6	7	.	.	13
/Symphoricarpos oreophilus h.t.	.	.	.	.	1	.	.	1
	75	161	10	84	56	31		416
Picea series								
/Equisetum arvense h.t.	3	.	2	7	2	1	.	15
/Clintonia uniflora h.t.								
-Vaccinium caespitosum phase	8	.	.	.	.	.	.	8
-Clintonia uniflora phase	16	.	.	.	.	.	.	16
/Physocarpus malvaceus h.t.	.	.	.	.	.	6	.	6
/Galium triflorum h.t.	.	3	.	1	8	9	.	21
/Vaccinium caespitosum h.t.	4	.	1	.	.	.	.	5
/Senecio streptanthifolius h.t.								
-Pseudotsuga menziesii phase	.	.	1	2	2	.	.	5
-Picea phase	.	.	.	5	.	.	.	5
/Linnaea borealis h.t.	.	1	.	5	4	11	.	21
/Smilacina stellata h.t.	.	1	.	4	1	4	.	10
	31	5	4	19	10	31		100

(con.)

Table B-1.--(con.)

Series/habitat type/phase	Montana forest region							
	NW	WC	NC	C	SW	SC	SE	Total
Abies grandis series								
/Xerophyllum tenax h.t.	5	1	.	.	.	.	.	6
/Clintonia uniflora h.t.								
-Clintonia uniflora phase	4	2	.	.	.	.	.	6
-Aralia nudicaulis phase	5	1	.	.	.	.	.	6
-Xerophyllum tenax phase	4	.	.	.	.	.	.	4
/Linnaea borealis h.t.								
-Linnaea borealis phase	3	2	.	.	.	.	.	5
-Xerophyllum tenax phase	3	.	.	.	.	.	.	3
	24	6						30
Thuja plicata series								
/Clintonia uniflora h.t.								
-Clintonia uniflora phase	13	2	.	.	.	.	.	15
-Aralia nudicaulis phase	8	1	.	.	.	.	.	9
-Menziesia ferruginea phase	6	1	.	.	.	.	.	7
/Oplopanax horridum h.t.	11	.	.	.	.	.	.	11
	38	4						42
Tsuga heterophylla series								
/Clintonia uniflora h.t.								
-Clintonia uniflora phase	27	.	.	.	.	.	.	27
-Aralia nudicaulis phase	11	.	.	.	.	.	.	11
	38							38
Abies lasiocarpa series (Lower subalpine h.t.s)								
/Oplopanax horridum h.t.	4	.	.	.	.	.	.	4
/Clintonia uniflora h.t.								
-Clintonia uniflora phase	18	11	3	.	.	.	.	32
-Aralia nudicaulis phase	12	4	2	.	.	.	.	18
-Vaccinium caespitosum phase	8	2	.	.	.	.	.	10
-Xerophyllum tenax phase	13	7	1	.	.	.	.	21
-Menziesia ferruginea phase	12	8	2	.	.	.	.	22
/Galium triflorum h.t.	.	10	4	5	.	.	.	34
/Vaccinium caespitosum h.t.	.	2	.	3	5	.	.	10
/Calamagrostis canadensis h.t.								
-Calamagrostis canadensis phase	.	8	.	1	8	6	.	23
-Galium triflorum phase	.	2	.	1	2	.	.	5
-Vaccinium caespitosum phase	3	1	.	1	2	.	.	7
/Linnaea borealis h.t.								
-Linnaea borealis phase	1	10	4	2	1	2	.	20
-Xerophyllum tenax phase	5	8	.	.	.	.	.	13
-Vaccinium scoparium phase	2	3	1	4	5	2	.	17
/Menziesia ferruginea h.t.	19	37	5	.	2	1	.	64

(con.)

Table B-1.-(Cont.)

Series/habitat type/phase								
Abies lasiocarpa series								
(Lower subalpine h.t.s)								
Tsuga mertensiana/Menziesia h.t.	8							
/Xerophyllum tenax h.t.								
-Vaccinium globulare phase	18							
-Vaccinium scoparium phase	3							21
Tsuga mertensiana/Xerophyllum h.t.	9							
/Vaccinium globulare h.t.								21
/Vaccinium scoparium h.t.								
-Calamagrostis rubescens phase								10
-Vaccinium scoparium phase	1							17
-Thalictrum occidentale phase				1				10
/Alnus sinuata h.t.			1					
/Calamagrostis rubescens h.t.			1	1		4		
/Clematis pseudoalpina h.t.			1	7	1	6		
/Arnica cordifolia h.t.			1	8	15			
/Carex geyeri h.t.								
-Carex geyeri phase					1			
-Pseudotsuga menziesii phase					1	3		
(Upper subalpine h.t.s)								
/Ribes montigenum h.t.								
Abies las.-Pinus albic./ Vaccinium scop. h.t.				9				
/Luzula hitchcockii h.t.								
-Vaccinium scoparium phase			4					
-Menziesia ferruginea phase	14		1					24
Tsuga mertensiana/Luzula h.t.								
-Vaccinium scoparium phase								
-Menziesia ferruginea phase								
(Timberline h.t.s)								
Pinus albicaulis-Abies lasiocarpa h.t.								30
Larix lyallii-Abies lasiocarpa h.t.s	5	29						36
Pinus albicaulis h.t.s								
		221	43	63				

Table B-1.--(con.)

Series/habitat type/phase	Montana forest region							
	NW	WC	NC	C	SW	SC	SE	Total
Pinus contorta series								
/Purshia tridentata h.t.	.	.	.	.	.	3	.	3
/Vaccinium caespitosum c.t.	.	4	1	2	5	.	.	12
/Linnaea borealis c.t.	1	4	.	2	6	4	.	17
/Vaccinium scoparium c.t.	1	6	.	5	6	2	.	20
/Calamagrostis rubescens c.t.	.	.	.	1	4	1	.	6
	2	14	1	10	21	10		58
Unclassified stands	11	8	3	12	3	6	.	43
Total number of plots	399	459	66	217	188	178	24	[1] 1,531

[1] This total includes 35 *Pinus contorta* community type plots also listed under *Pseudotsuga*, *Picea*, or *Abies lasiocarpa* habitat types.

APPENDIX C

National Forests, Indian Reservations, and
National Parks within each forest region in Montana

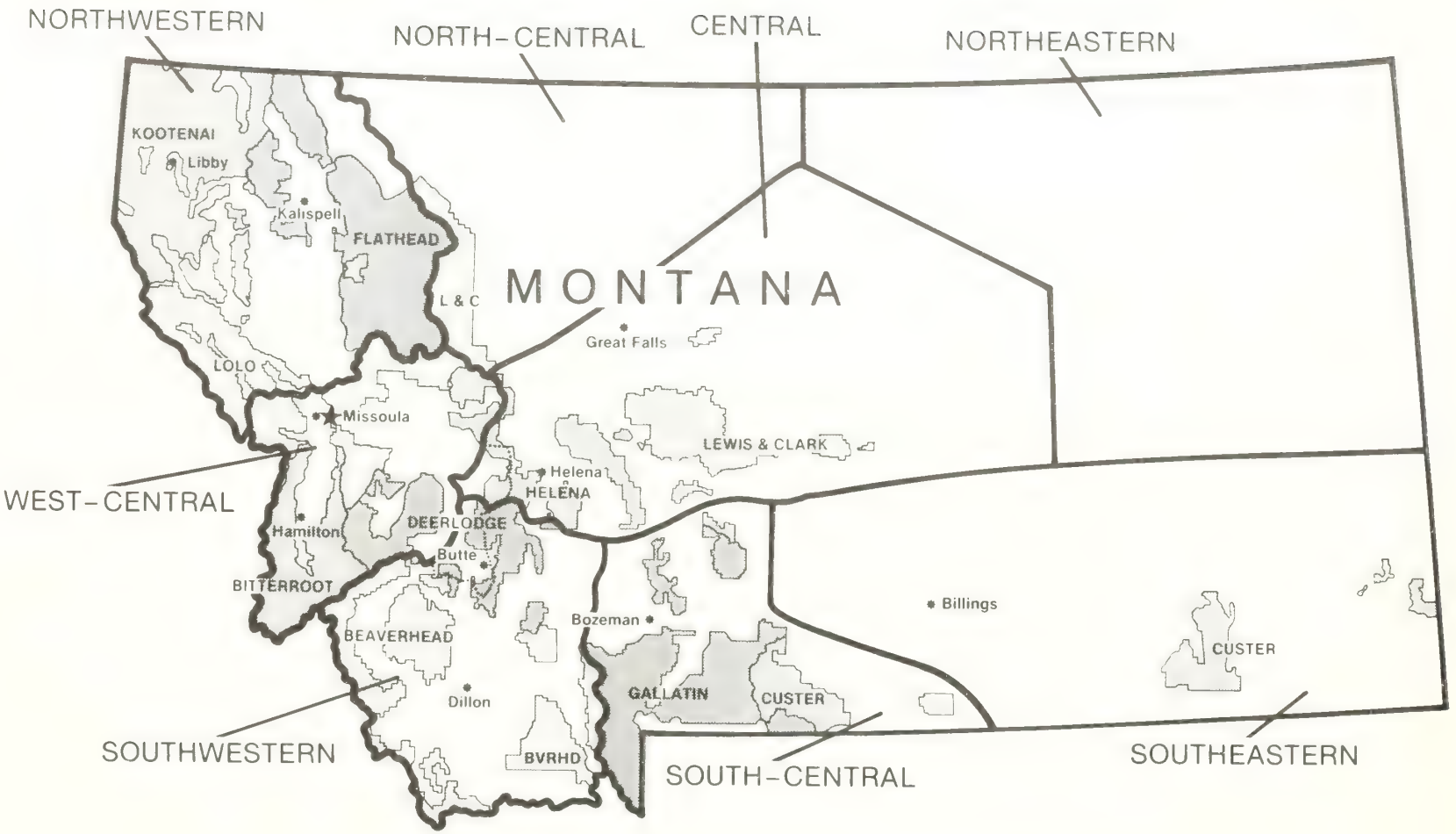

Figure C-1.--National Forests within forest regions in Montana.

National forests (fig. C-1), Indian Reservations, and Department of Interior lands within each forest region. (N.F. = National Forest; R.D. = Ranger District):

Forest region	
Northwestern	Flathead N.F. Kootenai N.F. Lolo N.F. (Thompson Falls, Plains, Superior, and W. and N. portions of Ninemile R.D.'s) Flathead Indian Reservation Glacier National Park (W. slope)
West-central	Bitterroot N.F. (Montana portion) Deerlodge N.F. (Philipsburg R.D., W. portion of Deer Lodge R.D.) Helena N.F. (Blackfoot River drainage portion) Lolo N.F. (Missoula, Seeley Lake, and S.E. portion of Ninemile R.D.)
North-central	[illegible] Front portion) Blackfeet Indian Reservation Glacier National Park (E. slope)
Central	Helena N.F. (except Blackfoot R. drainage) Lewis and Clark N.F. (except Rocky Mt. Front and Crazy Mts.) Fort Belknap (S. portion) and Rocky Boy Indian Reservation Chas. M. Russell National Wildlife Refuge (W. portion)
Southwestern	Beaverhead N.F. Deerlodge N.F. (except Philipsburg and W. portion of Deer Lodge R.D.'s)
South-central	Custer N.F. (Red Lodge R.D.) Gallatin N.F. Lewis and Clark N.F. (Crazy Mts. portion) Crow Indian Reservation (Pryor and Bighorn Mts. portion) Yellowstone National Park (Montana portion)
Southeastern	Custer N.F. (Montana portion except Red Lodge R.D.) Crow (except Pryor and Bighorn Mts.) and Northern Cheyenne Indian Reservation
Northeastern	Fort Belknap (N. portion) and Fort Peck Indian Reservation Chas. M. Russell National Wildlife Refuge (E. portion)

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In this paper, Montana is divided into eight geographic subdivisions called "forest regions," based on distributions of tree and undergrowth species and the relationship of these patterns to climate and topography. The regions serve as a geographic reference for describing patterns of forest vegetation across the State. Data on the distributions of plant species and habitat types and forest zonation are presented for each region.

KEYWORDS: forest ecology, forest classification, plant geography, Northern Rocky Mountains

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Northern Rocky Mountains

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

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PREDICTING SUCCESS OF PRESCRIBED FIRES IN PINYON-JUNIPER WOODLAND IN NEVADA

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Forest Service • U.S. Department of Agriculture

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Cooperative study between the
USDA Forest Service,
and
Nevada Agricultural Experiment Station

Intermountain Forest and Range Experiment Station
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RESEARCH SUMMARY

Prescribed burning is an inexpensive management tool which can be used for converting pinyon-juniper woodlands to brush-grassland communities that benefit wildlife and livestock grazing. One of the difficulties of prescribed burning is predicting whether or not conditions are right for a successful burn. In this study, 30 prescribed burns were attempted out of fire season from fall 1974 to fall 1976. These attempts were made during varied atmospheric conditions and in several pinyon-juniper communities, but only 12 of the 30 attempts were successful. An analysis of the burns showed that the success of a burn could be predicted accurately (89 percent) by adding together the maximum windspeed in miles per hour, the air temperature in degrees Fahrenheit, and the percentage of vegetation cover (windspeed [mi/h] + air temperature [°F] + vegetation cover [percent] = score). If the score thus obtained was less than 110, the fire would not burn; if it was greater than 130 it was too hazardous to light. Scores between 110 and 125 produced fires which needed continual retorching, and scores between 126 and 130 produced fires that carried by themselves and created clean burns. Fires were most successful in dispersed, scattered and dense pinyon-juniper stands, less successful in open and closed stands. The best ignition technique was to have two people walk perpendicular to the wind along the windward edge of the area to be burned headfiring and ignite trees using smudge pot lighters.

CONTENTS

	Page
INTRODUCTION	1
METHODS	1
Ignition	2
Evaluation of Fire Success	3
RESULTS	3
Pinyon-Juniper Communities	3
Prediction of Fire Success	8
CONCLUSION	10
PUBLICATIONS CITED	11

INTRODUCTION

Pinyon pine (*Pinus monophylla*) and juniper (*Juniperus osteosperma*) occupy approxi-
ately 14 percent of Nevada (Blackburn and Tueller 1970). Invasion of pinyon-juniper
ossibly due to past overgrazing and fire suppression often results in the elimination of
nderstory vegetation. This in turn decreases forage for livestock and wildlife. Pre-
cribed burning is an inexpensive method of converting small portions of pinyon-juniper
egetation to brush-grassland communities that benefit both wildlife and livestock graz-
ng (Aro 1971).

Most of the woodlands in Nevada have a large degree of nonuniformity due to the
bruptly changing topography, soil depth, aspect, and elevation. This nonuniformity
rovides many natural firebreaks in most pinyon-juniper stands and makes it easy to
elineate areas for prescribed burning.

This report provides burning guidelines for using prescribed fire as a management
ool in pinyon-juniper communities. The various pinyon-juniper communities have been
egregated and recommendations are made as to which communities are most responsive to
ire. From 1974 to 1976, 30 attempts were made to burn pinyon-juniper vegetation in
he spring and fall. Twelve of these attempts were successful in that the fire carried
eyond the ignition area through the vegetation leaving few if any unburned areas or
slands. The best ignition methods were determined, and a simple method for determining
urning success prior to ignition was developed from analyses of these burns.

METHODS

Burning attempts were made out of fire season at three locations: White River in
he White Pine District and Cherry Springs in the Lamoille District of the Humboldt
lational Forest; and Blackwell Canyon in the Bridgeport District of the Toiyabe National
orest (fig. 1). The majority of attempts and all the successful burns were in the
hite River area.

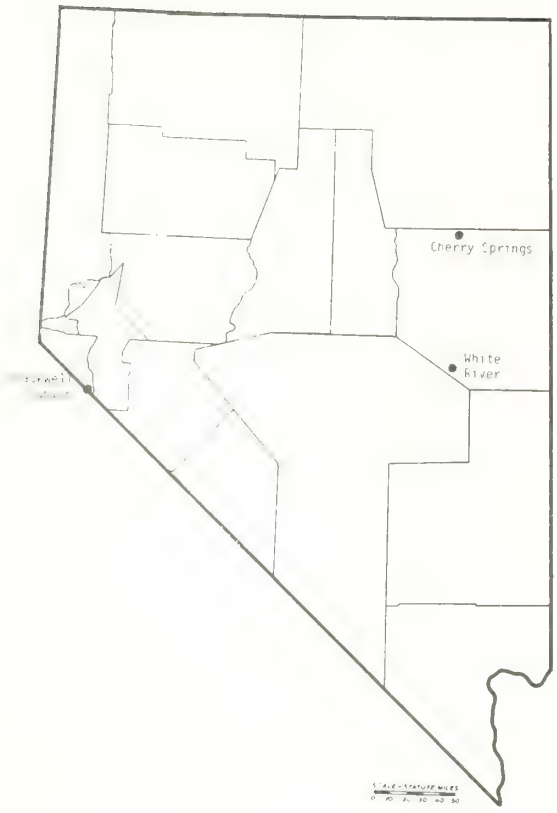

Figure 1.--Areas of experimental burning attempts from fall 1974 to fall 1976.

Ignition

Three tools for igniting trees were compared--conventional drip torches, flamethrowers, and the orchard heater lighter. The latter, also called the smudge pot lighter, was found to be the ideal tool (Bruner 1977) because its long spout gives a good pouring balance and provides some distance between the user and the flame. It emits a heavy stream of fuel which, when mixed 50-50 (50 percent gasoline and 50 percent diesel oil), remains burning on the bark or needles for 10 to 20 seconds. To ignite a tree, pour a heavy stream of burning fuel up and down the trunk from the ground up to 5 or 6 feet. The dead needles on the ground and any shrubs under the tree should be ignited while backing out from under the canopy on the windward side. By directly lighting several trees, the ambient temperature of the area increases rapidly and understory plants are ignited. It is this initial torch of several trees producing a flame length of 20 to 30 feet that is necessary to develop a fire which will carry and create a clean burn (fig. 2). Heat and flame are not generated fast enough if only the shrubs are lit, especially those in the tree interspaces. Two safety precautions of the tool are: gasoline must be well mixed with diesel oil and the antiflashback screen must be present in the spout.

Several techniques have been tried in igniting pinyon-juniper stands. The best method is to have two people walk perpendicular to the wind along the windward edge of the area to be burned (headfiring). The lead person can either leave unlit holes for the following person to light, or the two people can leap frog past one another. Either way, this has been the easiest and the most efficient way to start pinyon-juniper fires.

Figure 2.--A [illegible] this burn added to the simple score of 126.

Evaluation of Fire Success

The degree of success of each burn varied considerably in the 30 burning attempts (table 1). Objective rating of burn success is difficult in these highly volatile pinyon-juniper vegetation types; the consumption of fuel by the fire seems to be the same whether the fire carries well or whether only the immediate ignition area burns. For this reason, the success rating falls into three simple categories: (1) after the ignition area is lit, the fire carries by itself, burning the area clean, with only some retorching necessary; (2) the ignition area needs to be continually lit during the entire burn period and some unburned islands occur; (3) the fire does not carry beyond the ignition area.

RESULTS

Pinyon-Juniper Communities

When discussing prescribed fire it is important to categorize the various pinyon-juniper communities. Blackburn and Tueller (1970) describe five general communities of pinyon-juniper and give a species cover percentage for each named community. By adding a range of percent tree cover to those named communities, the following divisions were made: 0-2 percent open, 2-9 percent dispersed, 9-23 percent scattered, 23-35 percent dense, and 35+ percent closed.

Table 1.--*Summary of atmospheric conditions, soil and plant moisture, and burning success for 30 burning attempts in the White River, Cherry Springs, and Blackwell Canyon study areas from 1974 to 1976*

Burn date	Location	Time[1]	Burning conditions: Temperature	Relative humidity	Wind speed	Soil moisture[2]	Plant moisture[3]	Burn success[4]	Area burned
			°F	Percent	Mi/h	Percent	Percent		Acres
17 Nov 74	White River	1315	51	26	0-10	--	--	2	2
18 Nov 74	White River	1230	53	27	8-12	--	--	3	
24 Apr 75	White River	1400	60	26	5-25	13	50	1	18
2 May 75	White River	1445	58	20	0- 8	12	48	2	9
3 May 75	White River	1100	56	26	0-10	12	48	2	
9 May 75	White River	1510	65	16	2- 8	12	50	1	19
16 May 75	White River	1030	65	14	0- 5	12	49	2	3
28 May 75	Cherry Spgs	1430	53	32	3-10	13	54	3	
29 May 75	Cherry Spgs	1300	65	20	0-10	13	54	3	
12 Jun 75	White River	1400	77	8	0-12	9	47	1	9
17 Jun 75	Cherry Spgs	1200	54	90	0- 5	10	49	3	
24 Jun 75	Cherry Spgs	1215	67	5	10-35	8	49	3	
24 Jun 75	Cherry Spgs	1430	56	35	0- 5	8	49	3	
26 Jun 75	Cherry Spgs	1145	65	26	0- 8	8	48	3	
26 Jun 75	Cherry Spgs	1500	74	16	0- 6	8	48	3	
9 Oct 75	White River	1300	53	18	0-10	9	38	2	8
26 Oct 75	Cherry Spgs	1100	51	40	5-20	17	35	3	
15 Nov 75	White River	1400	55	12	0- 7	3	--	2	3
5 May 76	Blackwell Canyon	1300	78	7	0- 8	--	42	0	
10 May 76	White River	1720	70	17	0- 8	11	53	3	
11 May 76	White River	1630	70	23	0-10	11	53	3	
17 May 76	White River	1550	72	19	0-12	--	--	1	60
27 May 76	White River	1515	78	17	3-15	6	--	3	
28 May 76	Cherry Spgs	1400	72	19	2-12	5	--	3	
28 May 76	Cherry Spgs	1730	65	9	5-20	5	--	3	
22 Jun 76	White River	1600	66	20	6-18	2	46	1	25
23 Jun 76	White River	1500	71	12	4-15	2	46	1	45
9 Nov 76	White River	1300	56	28	0- 8	7	49	1	6
10 Nov 76	White River	1430	50	40	0	7	49	3	
9 Dec 76	White River	1150	36	52	2-10	11	49	3	

[1]Time at ignition.
[2]Sample 0-4 inches deep.
[3]Percent of green weight pinyon.
[4]0 = too hazardous to light; 1 = fire carried, clean burn; 2 = fire needed lighting assistance; 3 = would not burn.

Three of these five communities are unsuitable for prescribed burning. The open and dispersed communities (fig. 3) are excluded because of the small degree of influence the trees have on the understory vegetation of these communities. The closed stands (fig. 4) are excluded because of the difficulty in burning them out of fire season. Closed communities have few understory shrubs; consequently, hazardous conditions capable of producing a crown fire are necessary before these communities will burn successfully. Ten attempts to burn closed stands in this study were unsuccessful. One attempt (table 1, 24 June 75, 12:15) was made during hazardous conditions but still failed to carry the fire. Because of the hazards, closed stands should be pretreated by chaining, windrowing, or other means before attempting to burn them.

Two communities remain on which burning might best be concentrated--scattered and dense (fig. 5). Blackburn and Tueller (1970) state that the scattered community appears to be the point in the invasion pattern where pinyon and juniper start to exert their influence and begin to dominate the understory species. This causes a sharp reduction in the vigor and frequency of the understory. Pinyon and juniper in dense communities exert even more influence, dominating the understory to an even greater extent.

Figure 3.--Open pinyon-juniper communities (top) and dispersed pinyon-juniper communities (bottom) are not recommended for burning because trees are too sparse to have much influence on the understory vegetation.

Figure 4.--Closed pinyon-juniper communities are extremely difficult to burn out of fire season.

Figure 5.--Scattered pinyon-juniper community (top) and dense pinyon-juniper community (bottom). Many successful burns occurred in these vegetation types.

Prediction of Fire Success

There are many variable conditions at the time of each burn (table 1). Many of the atmospheric conditions compensate for each other; a low value of one can be offset by a high value of another. When maximum windspeed, air temperature, and percent vegetation cover are added together, this composite score becomes a good indicator of burning success in the scattered and dense pinyon-juniper communities (table 2). The score

Table 2.--*Composite score and burn ratings during 1974-76 burns at White River and Blackwell Canyon, Nevada*

Burn date	Windspeed	Temperature	Vegetation cover	Score[1]	Simple score rating[2]	Discriminant analysis rating[3]	Actual rating
	Mi/h	*°F*	*Percent*				
No burn prediction (score <110)							
9 Dec 76	10	35	49	94	3	3	3
10 Nov 76	0	50	51	101	3	3	3
Continual retorching necessary (score 110-125)							
15 Nov 75	7	55	56	118	2	2	2
9 Oct 75	10	53	56	119	2	2	2
16 May 75	5	65	50	120	2	2	2
10 May 76	8	70	43	121	2	3	3
2 May 75	8	58	56	122	2	2	2
3 May 75	10	56	56	122	2	2	2
Clean burn prediction (score 126-130)							
9 Nov 76	8	55	63	126	1	2	1
17 May 76	12	72	43	127	1	1	1
27 May 76	6	78	43	127	1	2	3
22 Jun 76	18	66	43	127	1	1	1
17 Nov 74	10	51	66	127	1	1	1
9 May 75	8	65	55	128	1	2	1
23 Jun 76	15	71	43	129	1	1	1
12 Jun 75	12	77	42	130	1	1	1
Hazardous burning conditions (score >130)							
24 Apr 75	25	60	46	131	[4] 1	1	1
3 May 76	8	78	48	134	0	--[5]	--[5]

[1]Score is derived by using the following formula: maximum windspeed (mi/h) + temperature (°F) + percent vegetation cover = score.

[2]3 = no burn (score <110); 2 = continual retorching necessary (score 110-125); 1 = clean burn, fire carries (score 126-130); 0 = too hazardous to burn (score >130).

[3]From Klecka (1975).

[4]This burn made one short run outside of the intended boundaries. It was felt that we were very close to or into the hazardous conditions for burning.

[5]The USFS Class I Fire Boss would not allow ignition this date, so no comparative or actual ratings were made.

is derived by simply adding maximum windspeed in miles per hour, air temperature in degrees Fahrenheit, and vegetation cover in percent (wind mi/h + °F + percent veg. cover = score). If metric measurements are used the formula is 0.6 (km/h) + 1.8 (°C) + percent veg. cover + 32 = score.

Considering the three fire class ratings of 1, 2, and 3 (table 2), a score of less than 110 will not provide conditions necessary for burning (class 3). A score of 110 to 125 indicates conditions prevail for a class 2 fire. A score of 125 to 130 indicates conditions are optimum for a class 1 or self-sustaining fire that will carry itself

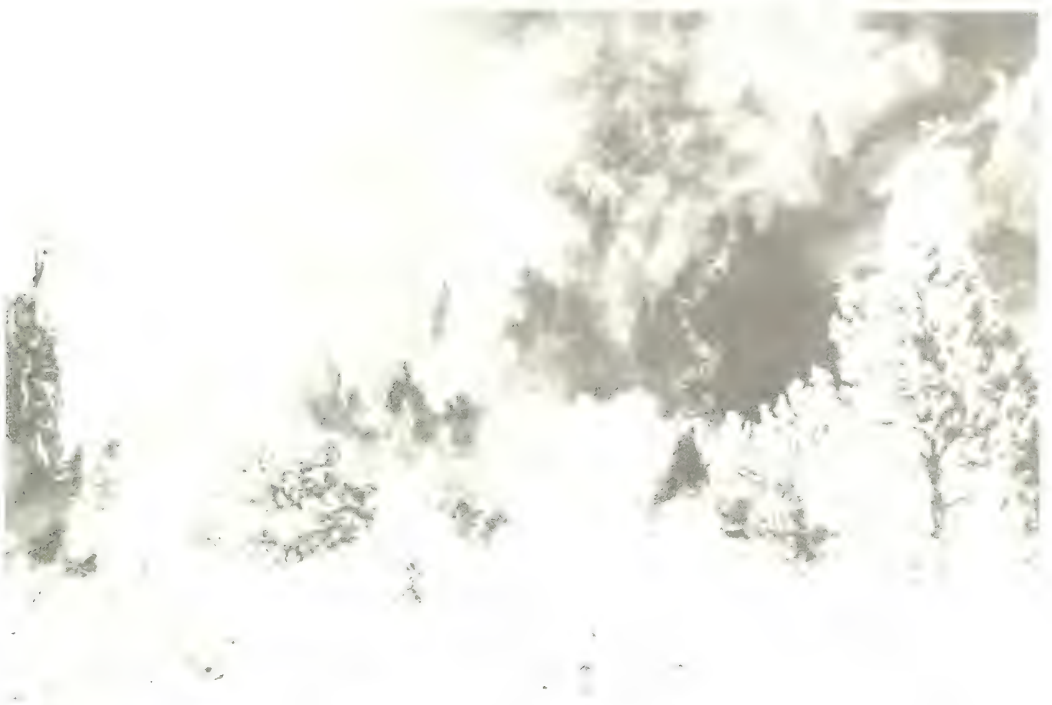

Figure 6.--A class 1 or self-sustaining fire capable of carrying through the vegetation. May 3, 1975, burn at Mill River, Nevada.

(fig. 6). A score higher than 130 indicates a hazardous condition in the scattered and dense pinyon-juniper communities when burning should not be attempted.

When these simple scores were compared on 17 burns (table 2), 15 of the 17 (88 percent) were correctly classified. A discriminant analysis (Klecka 1975) was used to construct a weighted score of the variables--wind, temperature, and cover--to separate the burns into three classes. This more sophisticated method correctly classified 82 percent of the burns. With more observations, these results would change; however, the simple score method compares very favorably with the discriminant analysis.

This simple scoring applies to the cooler months of April, May, October, and November, or anytime when air temperatures are below 75°F and windspeeds are above 5 mi/h. Total vegetation cover varied from 42 to 66 percent on all successful burns (table 2). Forb and grass cover was minimal in all areas.

There appears to be a narrow separation between conditions necessary for prescribed burning which will adequately carry a fire and those of a wildfire which develop concern

toward suppression. The score of 130 appears to be close to this separation point. those burning attempts made during the project, conditions above 131 were not tested no fires became dangerous or burned excessive acreages beyond the expected limits.

It is certain there are numerous and more complex variables involved in fire spr potential; however, this simple score seems to work as a general rule of thumb and it provides a guide for the land manager.

CONCLUSION

Land managers wanting to do out-of-fire-season burning are sometimes reluctant be cause they are not sure of the conditions needed to carry a fire. Many times, a day i spent in preparation and travel to the proposed burn site only to find that conditions are not adequate to carry a fire. A simple rule of thumb would aid in this burn or no burn decision. The managers needs to know only the sum of the maximum windspeed in miles per hour, the air temperature in degrees Fahrenheit, and the percent vegetative cover (mi/h + °F + percent veg. cover = score) to predict if his fire will be successf

A score of less than 110 will not provide conditions necessary for burning. A score of 110 to 125 indicates conditions prevail for burning; however, the area will need to be continually reignited during the entire burn period and unburned islands will occur. A score of 125 to 130 is optimum. After the ignition area is lit, the fire will carry by itself burning the area clean, with only some reignition necessary. A score above 130 indicates a hazardous condition in the scattered and dense pinyon-juniper communities when burning should not be attempted.

If the percent cover of vegetation is measured prior to burning and the desired wind direction is known for ignition points, the manager can predict his chances for a successful burn from the daily weather forecasts.

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Thirty prescribed burns were attempted in pinyon-juniper woodlands from fall 1974 to fall 1976. These attempts were made out of fire season, during varied atmospheric conditions, and in several pinyon-juniper communities. An analysis of the successful burns provided us with a method for predicting burning success from windspeed, air temperature, and vegetation cover. An igniting technique is also discussed.

KEYWORDS: Pinyon-Juniper ecology, prescribed fire, burning technique

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CHARACTERISTICS AND HYBRIDIZATION OF IMPORTANT INTERMOUNTAIN SHRUBS

III. SUNFLOWER FAMILY

E. Durant McArthur, A. Clyde Blauer,
A. Perry Plummer and Richard Stevens

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CHARACTERISTICS AND HYBRIDIZATION OF IMPORTANT INTERMOUNTAIN SHRUBS III. SUNFLOWER FAMILY

**E. Durant McArthur, A. Clyde Blauer,
A. Perry Plummer and Richard Stevens**

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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RESEARCH SUMMARY

Shrubs of the sunflower family are among the most common and important plants of the Intermountain area. In many valley, foothill, and mountain locations, composite shrubs, especially the sagebrushes and rabbitbrushes, provide the principal vegetation. These shrubs are invaluable as ground cover on natural and disturbed landscapes, as forage for wild and domestic herbivores, and as habitat for smaller creatures. The authors discuss and review vegetative, floral, and reproductive characteristics, hybridization, distribution and habitat, use, and division into subspecies entries for important Intermountain species. The following genera are covered: Artemisia, Chrysothamnus, Tetradymia, and Xanthocephalum (Artemisia arbuscula, A. bigelovii, A. cana, A. filifolia, A. frigida, A. longiloba, A. nova, A. pygmaea, A. rigida, A. rothrockii, A. spinescens, A. tridentata, A. tripartita, Chrysothamnus albidus, C. depressus, C. greeni, C. linifolius, C. nauseosus, C. parryi, C. vaseyi, C. viscidiflorus, Tetradymia canescens, T. glabrata, T. nuttallii, T. spinosa, Xanthocephalum microcephala, and X. sarothrae). Hybridization experiments and the possibility of plant improvement are discussed for section Tridentatae of Artemisia. A key to the taxa discussed is provided.

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The Snow Field Station, Ephraim, Utah, at which experiments were performed and observations made, is cooperatively maintained by the Intermountain Forest and Range Experiment Station, Utah State Division of Wildlife Resources, Utah State University, and Snow College.

CONTENTS

Page

INTRODUCTION 1

METHODS 2

CHARACTERISTICS OF THE GENUS ARTEMISIA (SAGEBRUSH) . 3

Artemisia arbuscula Nutt. (low sagebrush) 6
Artemisia bigelovii Gray. (Bigelow sagebrush) 9
Artemisia cana Pursh. (silver sagebrush) 10
Artemisia filifolia Torr. (sand sagebrush) 12
Artemisia frigida Willd. (fringed sagebrush) 13
Artemisia longiloba (Osterhout) Beetle (alkali sagebrush) . 16
Artemisia nova Nelson (black sagebrush) 17
Artemisia pygmaea Gray (pigmy sagebrush) 19
Artemisia rigida (Nutt.) Gray (stiff or scabland sagebrush). 20
Artemisia rothrockii Gray (timberline sagebrush). 23
Artemisia spinescens Eaton (budsage) 24
Artemisia tridentata Nutt. (big sagebrush) 26
Artemisia tripartita Rydb. (threetip sagebrush) 34
Artificial hybridization in section Tridentatae of Artemisia 35

CHARACTERISTICS OF THE GENUS CHRYSOTHAMNUS (RABBITBRUSH) 36

Chrysothamnus albidus (Jones) Greene (alkali or white flowered rabbitbrush) 39
Chrysothamnus depressus Nutt. (dwarf rabbitbrush) 39
Chrysothamnus greenei Nutt. (Gray) Greene (Greenes rabbitbrush) 41
Chrysothamnus linifolius Greene (spreading rabbitbrush). . 42
Chrysothamnus nauseosus (Pallas) Britt. (rubber rabbitbrush) 43
Chrysothamnus parryi (Gray) Greene (parry rabbitbrush) . 51
Chrysothamnus vaseyi (Gray) Greene (vasey rabbitbrush) . 53
Chrysothamnus viscidiflorus (Hook.) Nutt. (low rabbitbrush) 54

CHARACTERISTICS OF THE GENUS TETRADYMIA (HORSEBRUSH) 58

Tetradymia canescens DC. (Gray horsebrush) 59
Tetradymia glabrata Torr. & Gray (littleleaf horsebrush) . 60

Page

Tetradymia nuttallii Torr. & Gray (Nuttall horsebrush) . . 61
Tetradymia spinosa Hook. & Arn. (spiny horsebrush) . . . 62

CHARACTERISTICS OF THE GENUS XANTHOCEPHALUM (MATCHBRUSH, SNAKEWEED) 63

Xanthocephalum microcephala Shinners (small headed matchweed) 64
Xanthocephalum sarothrae Shinners (broom snakeweed). . . 64

LITERATURE CITED 66

APPENDIX 73

Compositae--Key to genera and species. 73

INTRODUCTION

The sunflower family is the largest family of flowering plants. Its many species ccur around the world (Benson 1957; Cronquist 1968). The family is well defined but iverse. Wagentiz (1976) stated, "The range of variability" of the sunflower family in life form and other vegetative characters is . . . impressive if we remember the family's) numerous annual herbs, herbaceous perennials, shrubs, and trees." It con- ains many beautiful, popular garden flowers, a large number of weeds, numerous useful ildland forbs, and some woody genera, including important browse species.

Four genera of this family, sagebrush (*Artemisia*), rabbitbrush (*Chrysothamnus*), orsebrush (*Tetradymia*) and matchweed (*Xanthocephalum*), are among the most common and mportant shrubs on western ranges. Approximately 11 percent (2,514,000 hectares or ,700 square miles) of Utah is dominated by various species of sagebrush. These species roduce the highest volume of forage of the various shrublands within the State (West 974). Approximately 109,400,000 hectares (422,000 square miles) in the Western States ave sagebrush in varying amounts growing on them (Beetle 1960). Horsebrush, matchweed, nd rabbitbrush, particularly rubber rabbitbrush (*C. nauseosus*) and low rabbitbrush *C. viscidiflorus)*, are commonly associated with sagebrush throughout the western nited States.

Shrubs of these genera provide critically needed ground cover on arid western anges, are important sources of browse for domestic livestock and big game, and serve s cover and forage for wildlife. Various forms of sagebrush and rabbitbrush may also e used for landscaping and for stabilizing and beautifying disturbed landscapes. oung wildings of both sagebrush and rabbitbrush transplant easily. Usually within to 7 years they are established sufficiently to reproduce naturally from seed. Both stablish well when aerially seeded (Plummer and others 1968; McArthur and others 1974; lummer 1977).

The purpose of this paper is to document what is known about shrubs of the sun- lower family in the Intermountain area, particularly their vegetative and flowering haracteristics, hybridization, distribution, and use. Most of the observational in- ormation and experimental data were gathered from the Intermountain area, especially rom Utah. The Intermountain area includes all of Utah, that portion of Arizona north f the Grand Canyon, most of Nevada, parts of California that lie within the Great asin, the sagebrush areas of southeastern Oregon, southern Idaho to the high mountain- us areas to the north, and the Red Desert area of southwestern Wyoming (Holmgren and eveal 1966). However, reference to and comments on species distribution and character- stics outside this area are made as appropriate.

Each species, its hybridization, distribution and habitat, and use are described n detail. Each genus and its species and subspecies included in this publication are rranged in alphabetical order. A taxonomic key (appendix) is given for the included enera, species, and subspecies. This paper is the third in a series on Intermountain hrub species; the first was on the Rose family and the second was on the Chenopod amily (Blauer and others 1975, 1976).

METHODS

Many accessions of Compositae genera have been transplanted into the uniform garde at the Snow Field Station in Ephraim, Utah (fig. 1), and at various other study and research areas. Observations and data collection on these plants and on plants occurring in many natural populations throughout the Intermountain area have provided the basis for this report. Much of the data collection has been for preparation of published and yet to be published reports (Plummer and others 1968; Hanks and others 1973, 1975; Plummer 1977; McArthur and Pope 1977; McArthur and Plummer 1978; McArthur and others 1978; McArthur 1979). Observations and collections were made so the floral and vegetative characteristics of the shrubs as well as their use, distribution, and habitat could be described and illustrated. Herbarium voucher specimens representing many of these populations have been deposited in the Shrub Sciences Laboratory Herbariu (SSLP). Photographic illustrations are from plants in natural settings and at experimental planting sites. Drawings of herbarium specimens are of plants from natural populations or from plants transplanted from natural populations onto the Snow Field Station. The latter are identified by culture numbers of the "U" series.

Literature pertaining to the Compositae genera we treat was surveyed and is cited throughout the paper. Existing keys and monographs were consulted in the preparation of our key.

In cases where the seeds per gram information was unknown, seeds were collected from 3 to 10 accessions. A minimum of 3 cleaned lots of 100 seeds each were counted and weighed on an analytical balance for each accession. The seeds-per-gram informatio was then extrapolated.

Hybridization experiments were first conducted in 1972 using hot water and chemica treatments in an attempt to induce male sterility in *Artemisia* and *Chrysothamnus*. Treatments were at different stages of phenological development, from early bud to just prior to anthesis. Hot water treatments following Hayes and others (1955) were from 40° C to 50° C for 2 to 10 minutes. The chemical treatment used was spraying Amchem's Ethrel (2-Chloroethylphosphonic acid) at concentrations of 100 to 12,000 parts per million on the inflorescences following Rowell and Miller (1971).

Figure 1.--Mature plants of composite accessions transplanted as wildings at Snow Field Station. (A) Chrysothamnus nauseosus *ssp.* salicifolius *(mountain rubber rabbitbrush). (B)* Artemisia rothrockii *(timberline sagebrush).*

Because neither the hot water nor the chemical treatments proved effective, subsequent efforts on section *Tridentatae* of *Artemisia* were in the form of mass pollination in white bakery bags or white, woven Terylene fabric bags (fig. 2). (Other types of pollination bags trapped excessive heat and humidity that caused excessive damage or death of enclosed plant tissue.) Four treatments were made: (1) a control where the bags were placed over some inflorescences and not opened again until the pollination season was over; (2) an intrapopulation treatment where an inflorescence containing pollen was inserted into the bag from another plant from the same accession; (3) an interpopulation treatment where pollen from another taxon was inserted into the bag--two of these were made on each plant; and (4) an open pollination where no bag was placed on the inflorescence but it was marked with a string so an equivalent seed source could be collected.

After pollen was inserted, all bags were shaken to facilitate pollination. This practice was continued every 2 or 3 days for about 10 days. About 3 or 4 weeks after pollinations, the bags were opened. The plants were monitored until seeds were ripe and about to shatter, at which time the seeds were collected. Seeds were cleaned in a forced-air seed separator. They were then counted in petri dishes with centimeter squares marked on the bottom. Exact counts were made when no more than 100 seeds were produced. Higher numbers (up to 5,000) were estimated by randomly distributing the seed in the petri dishes, counting a known area of the dish, and extrapolating. To test differences in pollination treatments, an analysis of variance followed by a multiple-range test was employed (Woolf 1968).

CHARACTERISTICS OF THE GENUS *ARTEMISIA* (SAGEBRUSH)

Artemisia is a large genus of approximately 200 species that occurs primarily in dry areas in the temperate regions of North America, North Africa, and Eurasia. *Artemisia* is most common in arid, steppe areas. Its extension south of the temperate zone usually is confined to mountainous habitats. Many of the species, especially in the western United States, are called sage or sagebrush. Old World names such as wormwood or mugwort have also been applied in the United States (Grieve 1931; Sampson and Jesperson 1963; Bailey Hortorium Staff 1976).

Figure 2.--Hybridization experiments with big sagebrush at the Snow Field Station. The pollination bags are of woven Terylene fabric with observation windows of clear plastic.

The genus consists of annual, biennial, and perennial herbs; subshrubs and shrubs of various sizes ranging from less than 2 dm up to 4.5 m. These plants contain volatile oils. All are aromatic, some strongly so; most emit a pronounced characteristic "sage" smell when the herbage is crushed. The glabrous to tomentose leaves are borne alternately. Leaves are entire to variously lobed or dissected.

Sagebrush flowers are very small and are borne in numerous small heads commonly arranged into panicles or sometimes racemes or spikelike inflorescences but never into cymes (see figure 5, page 7). Each head has a cuplike involucre made up of 2 to 4 series of dry, papery, closely overlapping bracts. Depending on the species, the heads contain either both ray and disc flowers or only disc flowers (fig. 3). The ray flowers, when present, are pistillate and fertile and have 2-cleft, more or less exserted styles. The disc flowers are perfect and fertile or sometimes sterile and each has a tubular to trumpet-shaped corolla with 5 stamens united by their anthers around the normally 2-cleft style. The ovary develops into a glabrous or resinous-granuliferous achene. Pappus is lacking in the vast majority of the species. Although basic chromosome numbers of x = 6, 7, 8, and 9 are known, x = 9 is the most common base number (Ward 1953; Kawatani and Ohno 1964; Wiens and Richter 1966). Polyploidy is common in the genus.

Natural hybridization among various taxa of western sagebrush seems to be widespread and common (Beetle 1960; Hanks and others 1973). Beetle (1960) believes several species and subspecies have originated through hybridization and subsequent polyploidy.

A number of *Artemisia* species and their subspecies are valuable browse plants, especially on winter and early spring ranges. These include *A. tridentata, A. nova, A. arbuscula, A. cana, A. spinescens, A. frigida, A. filifolia, A. longiloba, A. bigelovii* and *A. rothrockii*. These and others are also useful for controlling soil erosion. *Artemisia* species are also browse plants of considerable importance in steppes of Eurasia and North Africa (Polyakov 1961). Larin (1956) stated "representatives of *Artemisia* have the greatest fodder importance of all the Compositae . . . . They clearly dominate the desert (of the U.S.S.R.) both in their quantity in the vegetative cover and in their fodder importance." *Artemisia* is essential in the maintenance of sage grouse populations (Braun and others 1977) as well as populations of other birds and small animals. Members of the herbaceous *Artemisia ludoviciana* complex are particularly good for soil stabilization (Monsen 1975).

Some species (*A. mexicana, A. absinthium, A. cina*) have long been used medicinally, mainly as a remedy for roundworms and are thus commonly known as wormwood. Other

Figure 3.--A ray flower and two disc flowers (left) from an Artemisia bigelovii *flower head (12X).*

species are used for flavoring. Hopi Indians flavor [illegible] with *A. frigida* along with the corn (Kearney and Peebles 1960). In Europe, *A. absinthium* and *A. barrelieri* are used in preparation of the alcoholic beverages, absinthe and Algerian absinthe, respectively. Vermouth derives from a German appelation for wormwood. Tarragon (*A. dracunculus*) is used to flavor vinegar and as seasoning. [illegible] very foliage, interesting leaf patterns, and pleasant odor make several species popular as ornamentals. One of the most attractive ornamental shrubs is the California native, *A. pycnocephala*. An Old World introduction, *A. [illegible]*, [illegible] of our gardens. Oldman wormwood (*A. abrotanum*) has had long usage as an ornamental shrub (Sampson and Jesperson 1963). More recently, *A. caucasica* has been introduced to this country and is finding use as an attractive prostrate border plant.

Classically, *Artemisia* has been taxonomically divided into four sections or subgenera (*Abrotanum*, *Absinthium*, *Dracunculus*, and *Seriphidium*). These sections are recognized primarily on the basis of flower characteristics--absence or presence and fertility or infertility of disc and ray flowers (see McArthur and Plummer 1978; and McArthur 1979 for review). We prefer to recognize the four sections: *Artemisia*, *Dracunculus*, *Seriphidium*, and *Tridentatae* (table 1). In this scheme, *Abrotanum* and *Absinthium* are combined to form *Artemisia* (Polyakov 1961). This union seems natural because the original separation was based only on the difference in hairiness of the floral receptacle. *Tridentatae* was recognized as being separate from *Seriphidium* on the basis of disjunct present and past distribution patterns, different basic karyotypes, and chemotaxonomic differences (McArthur and Plummer 1978).

Table 1.--Taxonomic sections of *Artemisia*

Classical section[1]	Modern sections[2]	[illegible] characteristics	[illegible]	Species mentioned
Absinthium	Artemisia	Pistillate ray flowers, perfect disc flowers, predominantly herbaceous but a few are woody.	Eurasia, North Africa, North America.	*A. absinthium*
Abrotanum				
				A. barrelieri
Dracunculus	Dracunculus	Pistillate ray flowers, staminate disc flowers; [illegible]	Eurasia, [illegible]	
Seriphidium	Seriphidium	Ray flowers lacking, [illegible]	[illegible]	
	Tridentatae	[illegible]	[illegible]	

[1] Pertains to [illegible] (Beetle 1960, McArthur [illegible]).
[2] Pertains to [illegible] (Beetle 1960, McArthur and [illegible]).
[3] Two [illegible] *A. mendozana* from Argentina.

Figure 4.--Mountain l
sagebrush (Artemisi
tridenta a *ssp.* vas
growing in a luxuri
stand of smooth bro
(Bromus inermis) *ir*
Ephraim canyon, Utc

Artemisias contain a variety of natural chemical products, most notably terpeno and phenolics. Many individual compounds have been isolated and identified, particu in recent years. Terpenoids include the monoterpenes of the essential oils that pro the characteristic odors of sagebrushes and wormwoods (Guenther 1952; Halligan 1975; Buttkus and others 1977; Scholl and others 1977). Sesquiterpene lactones are anothe class of terpenoids common in the *Artemisias* (Kelsey and others 1973; Geissman and I 1974; Rodriguez and others 1976). Two principal classes of phenolic compounds are p sent, the coumarins (Shafizadeh and Melnikoff 1970; Brown and others 1975) and the flavonoids (Rodriguez and others 1972; Segal and others 1973; Brown and others 1975).

In addition to terpenoids and phenolics, a third class of chemicals--the alkane hydrocarbons--was studied by Bachelor and others (1972). The rich array of natural chemical products in *Artemisia* has proven to be useful in delimiting taxonomic bound (Hanks and others 1973; Kelsey and others 1973; and Geissman and Irwin 1974). Altho the physiological importance of many of the natural chemical products is unknown, so have been implicated in the allelopathic properties of *Artemisia*. Many *Artemisias* h allelopathic qualities; under certain conditions they may chemically inhibit growth seedlings and established plants of competitive species, and even growth of their ow seedlings. These allelopathic qualities might contribute to the dominant position o sagebrushes and wormwoods in many communities. *A. californica, A. absinthium, A. he alba, A. vulgaris, A. tridentata,* and *A. cana* have been shown to have allelopathic p erties (Schlatterer and Tisdale 1969; Halligan 1975; Friedman and others 1977; Hoffm and Hazelett 1977; Weaver and Klarich 1977). Nevertheless, in many instances *Artemi* are part of communities rich in species (fig. 4). So, the significance of allelopat in *Artemisia* communities remains in doubt.

The natural chemical products might account for the differential palatability a *Artemisia* taxa (Hanks and others 1973; Sheehy and Winward 1976; Scholl and others 19

Artemisia arbuscula Nutt. (low sagebrush[1])

Low sagebrush is a low, spreading, irregularly branched shrub up to 5 dm high (f 5a). The slender erect twigs are densely canescent, but may become nearly glabrous thus darker green in late summer. The plant layers infrequently.

[1]Also called little sagebrush, scabland sagebrush, dark sagebrush.

gure 1.--Artemisia [illegible]. (A) A. [illegible], [illegible]; [illegible], [illegible]; [illegible], [illegible]. (B) A. bigelovii, [illegible]; [illegible], [illegible]; [illegible], [illegible]. (C) A. nova, [illegible]; [illegible], [illegible]; [illegible], [illegible]; A. [illegible], [illegible]; [illegible]; [illegible]'s [illegible], [illegible]; [illegible], [illegible].

Figure 6.--Low sagebrush (A. arbuscula) *growing on the rocky flanks of Indian Peak, Beaver Co., Utah.*

Leaves are broadly cuneate or fan-shaped, 0.5 to 1.5 cm long, 0.3 to 1 cm wide and are usually 3 (occasionally 4 to 5) toothed or cleft at the apex. Leaves on the upper part of the flowering shoots may become entire.

Flower heads are grouped into elongated, narrow racemose panicles (fig. 5a). The heads usually contain from 5 to 11 disc flowers with corollas 3 to 4 mm long. The 10 to 15 involucral bracts are canescent. Flowering occurs from August to September, depending upon strain and elevation. Seed ripens in October and November. Cleaned seed averages 2,160 per gram (980,000 per pound) (Deitschman 1974).

Hybridization.--This species has a basic chromosome number of $x = 9$. Both diploid ($2n = 18$) and tetraploid ($2n = 36$) forms are known (Ward 1953; McArthur and Plummer 1978). Intermediates between low sagebrush and both *A. tripartita* ssp. *tripartita*, and *A. tridentata* ssp. *tridentata* have been reported by Beetle (1960). Hanks and others (1973) found chromatographic evidence of hybridization between low sagebrush and *A. tridentata* ssp. *vaseyana*. Ward (1953) united both low sagebrush and black sagebrush (*A. nova*) into a single species partly because he felt they intergrade into one another.

However, Ward (1953) found that most specimens of black sagebrush he examined were tetraploid, whereas most specimens of low sagebrush were diploid. This difference in chromosome number could be a barrier to free interbreeding, because populations of the two species with the same number of chromosomes are not known to occur together. In fact, the two species rarely occur together (Ward 1953). On the basis of field collections, Beetle (1971) argued persuasively for separate species status for the two sagebrushes.

A dwarf form of *A. arbuscula* occurs in the Stanley Basin area of Idaho, the Jackson Hole, Wyoming area, and perhaps in other locations. Beetle (1959, 1960) named this form *A. arbuscula* ssp. *thermopola*--hotsprings sagebrush. Beetle speculated that this form arose as the result of hybridization between typical *A. arbuscula* and *A. tripartita*.

Distribution and habitat.--Low sagebrush grows on dry, sterile, rocky, often alkaline soils between 700 and 3,500 meters (2,300 and 11,500 feet) approximately 10,135,000 hectares (39,112 square miles) in 11 western States (Beetle 1960; Ward 1953) (fig. 6). In the warmer, drier parts of its range, particularly in Nevada, it may grow well into the mountains above 3,000 meters (9,800 feet). In some areas, for example, east central Idaho, low sagebrush occurs on disjunct low and high elevation bands (E. F. Schlatterer, letter 12/1/77).

Figure 7.--Bigelow sagebrush (A. bigelovii) growing at the Snow Field Station. The ruler is 30 cm long.

Low sagebrush ranges from southern Colorado to western Montana and west throughout Utah and Idaho to northern California, Oregon, and Washington. Type locality is listed as "arid plains of Lewis (Snake) River" (Beetle 1960). Normally its sites are drier and more rocky than those on which big sagebrush occurs. Low sagebrush and black sagebrush rarely occur in intermixed stands, for example, the Lost River-Lemhi Range area of Idaho (E. F. Schlatterer, letter 12/1/77). In areas where the distribution of these two species overlaps, low sagebrush is usually found in the more moist habitats or at slightly higher elevations than black sagebrush (Ward 1953).

Use.--On winter ranges and to a limited extent on summer ranges, low sagebrush is browsed by big game and livestock. There is considerable variation in how animals browse it in different locations. In Nevada, the gray-green form may be heavily browsed while the green form is only lightly browsed (Brunner 1972). Sage grouse also apparently prefer the lighter form to the darker one. Similarly, black sagebrush also has two color morphs, with the light (gray-green) one preferred by browsing animals.

Artemisia bigelovii Gray. (Bigelow sagebrush)

Bigelow sagebrush is a low shrub 2 to 4 dm high with numerous spreading branches. The flowering stems are slender and erect and bear inflorescences that are long, narrow panicles with short, recurved branches (figs. 5b, 7). New growth is covered with a silvery-canescent pubescence.

The leaves of vegetative branches are similar to those of big sagebrush. They are narrowly cuneate, 1 to 2 cm long, 2 to 5 mm wide, and normally tridentate, but may show various abnormal tips. The odor of crushed leaves is mild like that of mountain big sagebrush (*A. tridentata* ssp. *vaseyana*).

The heads are arranged into elongated, narrow panicles and normally contain 1 but occasionally 0 to 2 ray flowers and 1 to 3, usually 2, disc flowers (fig. 3). The turbinate involucre consists of 8 to 12 short, densely tomentose bracts 2 to 4 mm long and 1.5 to 2.5 mm broad. Flowering occurs from August to October. Cleaned seed averages 5,975 per gram (2,710,000 per pound).

Bigelow sagebrush closely resembles and is often mistaken for low forms of big sagebrush produced by overgrazing and burning. In contrast to big sagebrush, however, it has ray flowers. Furthermore, lobes of *A. bigelovii*'s vegetative leaves are always more shallow and more sharply dentate than those of big sagebrush.

*Figure 8.--Bigelow sagebrush (*A. bigelovii*) growing with fourwing saltbush (*Atriplex canescens*) in a gravelly draw near Bicknell, Wayne Co., Utah.*

A. bigelovii is normally free of insect galls and rust diseases that are common in the other taxa of the section *Tridentatae* (Beetle 1960).

Hybridization.--This species has a basic chromosome number of $x = 9$. Both diploid ($2n = 18$) and tetraploid ($2n = 36$) forms are known (Ward 1953; McArthur and Plummer 1978).

Bigelow sagebrush and basin big sagebrush are often found growing together but are not known to cross or intergrade.

Distribution and habitat.--Bigelow sagebrush has a more southerly distribution than other sagebrushes. It is one of the most drought-resistant sagebrushes. It occurs over approximately 8,810,000 hectares (34,010 square miles) through western Texas, southern Colorado, New Mexico, Arizona, Utah, Nevada, and California in canyons, gravelly draws and dry flats from 900 to 2,400 meters (3,000 to 7,900 feet) (Ward 1953; Beetle 1960; Kearney and Peebles 1960) (fig. 8). The Bigelow sagebrush type locality is recorded as "rocks and canyons on the Upper Canadian, Texas" (Beetle 1960).

This species is often found mixed with big sagebrush, black sagebrush, leafless green rabbitbrush (*Chrysothamnus nauseosus* ssp. *junceus*), shadscale (*Atriplex confertifolia*), and especially matchbrush (*Xanthocephalum* [*Gutierrezia*] *sarothrae*) (Hall and Clements 1923).

Use.--Bigelow sagebrush is palatable to livestock and game in all areas where it occurs. Its twigs are less woody, its odor milder, and its taste is less bitter than most of the big sagebrush complex (Hall and Clements 1923).

Artemisia cana Pursh. (silver sagebrush[2])

Silver sagebrush is an erect, freely branched, rounded shrub up to 1.5 meters tall. Older branches have dark-brown, fibrous bark while younger branches are covered with a dense white to yellowish-green tomentum.

[2]Other common names are white sagebrush, hoary sagebrush, hoary silver sagebrush.

Figure 9.--Leaves of silver sagebrush. Top, A. cana *ssp.* viscidula; *bottom.* A. cana *ssp.* cana. *The longer leaf is 4 cm long.*

Leaves on the vegetative branches are 1 to 10 mm wide and 2 to 8 cm long, linear to linear-oblanceolate, entire or occasionally with 1 or 2 irregular teeth or lobes, silver-canescent becoming slightly viscid with age (figs. 9, 10). Leaves on the flowering stems are similar, but they may be slightly smaller, especially on the upper parts of the stems. The foliage emits a mild to pungent aromatic odor when crushed.

Numerous heads are arranged into dense, narrow, leafy panicles, sometimes reduced to raceme or spikelike inflorescence (fig. 10). Each head contains 4 to 20 disc flowers. Ray flowers are lacking. Achenes are granuliferous. Blooming occurs during August and September. Cleaned seed averages 4,900 per gram (2,220,000 per pound).

Hybridization.--Silver sagebrush occurs in both diploid ($2n$ = 18) and tetraploid ($2n$ = 36) forms (Ward 1953). Putative natural hybridization between subspecies of A. *cana* (*cana* and *viscidula*) and other shrubby species of *Artemisia* have been reported (Ward 1953; Beetle 1960; Hanks and others 1973).

Distribution.--Silver sagebrush occurs over approximately 13,790,000 hectares (53,221 square miles) from British Columbia to Saskatchewan, south to Nebraska, Colorado, and New Mexico, and west to Oregon and California on valleys, plains, foothills, and mountains up to 3,050 meters (10,000 feet) (Beetle 1960).

Use.--Silver sagebrush is important throughout its range as a browse shrub and is used quite extensively by livestock and big game, particularly when other food is scarce. In the western Great Plains area, silver sagebrush is an important antelope survival food. Like big sagebrush, this species has been used by white settlers and Indians for fuel. Silver sagebrush has been used as an ornamental in England (Hall and Clements 1923).

Figure 10.--Mountain silver sagebrush (A. cana *ssp.* viscidula) *on Targhee National Forest, Sublette Co., Wyoming, showing leaves and flower heads.*

Subspecies.--Artemisia cana ssp. *cana* (silver sagebrush) is an erect, rounded, freely branched shrub up to 1.5 meters tall. It layers whenever conditions are suitabl This subspecies may spread rapidly, particularly after burning, by rootsprouting and b rhizomes (Beetle 1960). Leaves of the vegetative branches are linear-oblanceolate, entire or rarely with 1 or 2 irregular teeth or lobes, 1 to 10 mm wide, 2 to 8 cm long, and are densely silky-canescent (fig. 9). Crushed foliage emits a pungent turpentine odor (Ward 1953; Beetle 1960). Flower heads are usually arranged into dense, leafy pa icles and may contain from 5 to 20 disc flowers. Blooming occurs during September, an the seeds ripen during October and November. Putative natural hybrids between subspec *cana* and both basin and mountain big sagebrush have been found (Ward 1953; Beetle 1960 Subspecies *cana* has a more eastern distribution than subspecies *viscidula*. It occurs from southern Canada southward, but mostly east of the Continental Divide, through Montana, the Dakotas, Wyoming, western Nebraska, and northern Colorado. Its type locality is "on the bluffs, Missouri River" (Beetle 1960).

Artemisia cana ssp. *viscidula* (mountain silver sagebrush) is an erect shrub that readily layers. It usually is not more than 1 meter tall. Leaves on the vegetative branches are 1 to 5 mm wide, up to 7 cm long (fig. 9), and are often crowded in dark-green clusters. The leaves typically are simple and entire but occasionally are variously toothed or lobed. This subspecies varies in appearance, but is always darke green than mountain big sagebrush with which it is often growing (Beetle 1960). Moun-tain silver sagebrush is distinguished from subspecies *cana* by its smaller, darker gre leaves, its lower stature, and more western distribution. Flower heads are arranged into dense, short raceme or spikelike inflorescences 1 to 3 cm long. Each head contai from 4 to 15 disc flowers. Flowers bloom during August and September. Seed matures during October and November. Putative natural hybrids involving this subspecies and *A tripartita* ssp. *tripartita*, *A. tridentata* ssp. *vaseyana*, and *A. tridentata* ssp. *triden tata* have been found (Beetle 1960; Hanks and others 1973). Beetle (1960) believes *Artemisia argilosa* may have arisen from a cross between *A. cana* ssp. *viscidula* and *A. longiloba*, and that *A. tridentata* ssp. *vaseyana* f. *spiciformis* may have developed from a cross between *A. cana* ssp. *viscidula* and *A. tridentata* ssp. *vaseyana*. Mountain silv sagebrush occurs in mountainous regions around 2,100 meters (6,900 feet) and above. It is usually found along streamsides and in areas of heavy, lingering snowpack from the southwest corner of Montana, south along the Continental Divide to New Mexico, and west to Arizona, Nevada, Utah, and Idaho. Mountain silver sagebrush type locality is Routt County, Colorado (Beetle 1960). A similar subspecies, *A. cana* ssp. *bolanderi* (Bolander silver sagebrush), occurs in extreme western Nevada and in California and Oregon. It is more canescent than ssp. *viscidula* and grows on poorer drained, usually more alkaline soils than does *viscidula* (Beetle 1960).

Artemisia filifolia Torr. (sand or oldman sagebrush)

Sand sagebrush is a round, freely branching shrub up to 1.5 meters tall (fig. 11) Young branches are covered with a canescent pubescence while the older stems are cover by a dark-gray or blackish bark.

The filiform silvery-white canescent leaves are 3 to 8 cm long, less than 0.5 mm wide, entire or ternately divided into filiform divisions, and are often fascicled (fig. 12a).

Numerous, nodding heads containing 2 or 3 fertile, pistillate ray flowers and 1 t 6 perfect but sterile disc flowers are arranged into leafy, narrow panicles. Each hea is subtended by 5 to 9 canescent involucral bracts. Both the receptacle and achenes a glabrous. Flowers bloom during August and September. Seed ripens from October to December. Cleaned seed averages 6,910 per gram (3,135,000 per pound).

Hybridization.--Sand sagebrush has a chromosome number of $2n = 18$ (McArthur and Pope 1977). It is a distinctive taxon that is not known to hybridize with other *Artemisias*. Ecotypic selection and subsequent hybridization and development might be possible. Hall and Clements (1923) suggested that birdfoot sagebrush (*A. pedatifida*)

Figure 11.--Sand sagebrush (A. filifolia) growing near Moccasin, Mohave Co., Arizona.

s the closest ally to sand sagebrush. Birdfoot sagebrush is a low perennial subshrub ith limited distribution on dry plateaus and ridges in Wyoming and Idaho, and possibly n Montana. In gross morphology, sand sagebrush and birdfoot sagebrush little resemble ne another, but their floral characteristics are quite similar. Their distributions o not presently overlap and no intermediates between the two have been found.

Distribution and habitat.--Sand sagebrush is an excellent indicator of sand and is robably the most widespread shrub on sand dunes and sandhills from Nebraska to Arizona Hall and Clements 1923). It occurs from Nevada and Utah east to Wyoming and western lebraska and south to Texas, Arizona, and Chihuahua, Mexico.

Use.--The browse value of sand sagebrush depends on where it grows. It is seldom aten in grasslands where other food is adequate, but in more arid, desert regions, it s often heavily used (Hall and Clements 1923). This species helps prevent wind erosion y helping to stabilize light sandy soils.

Artemisia frigida Willd. (fringed sagebrush[3])

Fringed sagebrush is a fragrant, aromatic, mat-forming perennial subshrub 2 to 5 m tall (fig. 13), the lower woody stems are spreading and often much branched. Adventitious rooting is common when stems contact the soil. The upper herbaceous stems are erect and leafy. The whole plant is densely silvery-canescent.

The numerous small silky-canescent leaves are 6 to 12 mm long, and are 2 or 3 times pinnately divided.

This species has a deep perennial taproot with numerous extensive laterals that help it withstand drought. This root system is also useful in stabilizing gullies and preventing soil erosion.

Numerous small flower heads are borne in nodding racemes or open panicles (fig. 2b). Small, densely hairy involucral bracts occur in several series around each flower head. Each head contains 10 to 17 outer, seed-producing, pistillate, ray flowers and numerous (25 to 50) tubular-funnelform, perfect, seed-producing disc flowers. Flower receptacles are densely villous.

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[3]Also called estafiata, prairie sagewort, fringed wormwood, pasture sagebrush, Arctic sagebrush, mountain sagebrush, wild sagebrush, and worm sagebrush.

Figure 12.--Artemisia *species.* *(A)* A. filifolia, *Culture U7, Kanab, Kane Co., Utah (0.8X).* *(B)* A. frigida, *Culture U8, Soldier Summit, Wasatch Co., Utah (1.1X).* *(C)* A. spinescens, *McArthur 115, Ferron, Emery Co., Utah (0.9X).* *(D)* A. tripartita ssp. tripartita, *Culture U1, Blue Lake, Humboldt Co., Nevada (1.0X).*

gure 17.--Fringed sagebrush (A. frigida) growing at Black Mesa, Gunnison Co., Colo.

Fringed sagebrush blooms from July at high elevations to November at lower elevations. Seed matures between September and December. Cleaned seed averages 8,545 per am (3,875,000 per pound).

Hybridization.--Fringed sagebrush is known only as a diploid, $2n = 18$ (Mulligan d Cody 1972; McArthur and Pope 1977). Numerous ecotypes of *A. frigida* are known over s broad range. It is not known to hybridize with other *Artemisias*.

Distribution and habitat.--Fringed sagebrush is probably the most widely distributed and abundant species of *Artemisia*. Its range extends from Mexico northward through st of the western United States and western Canada into Alaska and Siberia (USDA Forest Service 1937).

Fringed sagebrush is a common plant of the high plains along the eastern slope of e Rocky Mountains, but also occurs in valleys and mountains. It is most abundant in e eastern and northern parts of its range. This species ranges from low, semidesert lleys to more than 3,350 meters (11,000 feet) elevation throughout the Rocky Mountain d Intermountain regions.

Fringed sagebrush inhabits a wide variety of sites. Most typically, it grows in ll sunlight in dry, coarse, shallow soils. On winter ranges in western Utah and stern Nevada, fringed sagebrush may occur in dense stands along shallow depressions at collect moisture from summer rains. In such areas, it is frequently associated th winterfat (*Ceratoides lanata*), shadscale, and rabbitbrushes (*Chrysothamnus* spp.). plains, foothills, and mountain slopes, this species may be associated with a variety grasses and forbs as well as with various shrubs such as big sagebrush, Bigelow sagebush, sand sagebrush, and especially in overgrazed areas, with broom snakeweed. It is common understory plant in ponderosa pine (*Pinus ponderosa*) in several western States.

Use.--The forage value of fringed sagebrush varies considerably with location and season. Its value as browse is highest in late fall, winter, and early spring on western ranges where it is eaten readily by big game and livestock (USDA Forest Service 1937). It is also important food for sage grouse (Wallestad and others 1975). In other areas, such as the grasslands of the Northwest and Great Plains, fringed sagebrush may be less palatable and occasionally invades deteriorated grasslands. However, on the Great Plains, fringed sagebrush is an important winter antelope food, and is used to a lesser extent the year round (E. F. Schlatter, letter 12/1/77).

This species has strong reproductive qualities and is a good pioneer shrub for stabilizing disturbed areas. It has excellent reproduction from seed, and young plants or segments of old plants are readily transplanted in early spring. Fringed sagebrush has some value as a medicinal plant (Hall and Clements 1923).

Artemisia longiloba (Osterhout) Beetle (alkali sagebrush)

Alkali sagebrush is a low shrub up to 4.5 dm tall. It has lax, spreading stems that frequently layer. The bark is dark brown to black on the older stems. The whole plant has a dark gray-green appearance (Beetle 1960).

Leaves on the vegetative stems are broadly cuneate, up to 2 cm long, and are deeply 3-lobed. Leaves of the flowering stems are similar but smaller on the upper part of the plants. Crushed foliage emits a pungent odor similar to that of camphor, in the spring, and to hydraulic fluid in the fall (Brunner 1972).

This species is readily distinguished from other low sagebrushes by its large heads and early blooming period (Beetle 1959) (fig. 14). Its heads contain 6 to 11 disc flowers and are 3 to 5 mm broad as opposed to 3 mm or less for other low sages. Alkali sagebrush blooms approximately a month earlier than other low sagebrushes. It flowers during mid-June to mid-July and its seed ripens in August. Cleaned seed averages 5,850 per gram (2,655,000 per pound).

Hybridization.--The chromosome number of *A. longiloba* is $2n = 18$ (McArthur and Pope, data on file at the Shrub Sciences Laboratory, Provo, Utah). Natural hybrids are not known, probably because this species flowers earlier than associated sagebrushes.

Beetle (1960) points out that this species has in the past been confused with *A. cana* because of its large heads; with *A. tridentata* because of its broadly cuneate, 3-lobed leaves; and with *A. arbuscula* because of its dwarf size.

Figure 14.--Alkali sagebrush (A. longiloba) growing at Wahsatch Station, Summit Co., Utah. Note the large flower heads.

igure 15.--Fenceline contrast which illustrates sheep browsing on alkali sagebrush (A. longiloba) in Echo Canyon, Summit Co., Utah.

Distribution and habitat.--Unlike other sagebrushes, alkali sagebrush characterstically grows in heavy, highly impermeable soils derived from highly alkaline shales, ut also it is frequently found on the lighter, limy soils. It occurs between 1,800 nd 2,450 meters in elevation (5,900 to 8,000 feet) over 1,325,000 hectares (5,120 quare miles) along the foothills of the ranges forming the Continental Divide from outhwestern Montana, south through Wyoming to northwestern Colorado, and scattered estward to Utah, Nevada, Idaho, and Oregon (Beetle 1960).

Use.--Beetle (1960) reports that alkali sagebrush ranges are often used for lambng grounds. We have found this shrub heavily grazed in Echo Canyon, Utah, and around vanston, Wyoming (fig. 15). In this area *A. longiloba* is referred to as "sweet sage." runner (1972) reported this species is not heavily used by browsing animals or sage rouse in Nevada.

Alkali sagebrush may be useful in rehabilitating basic mine spoils like those roduced from oil shale works. We have observed it invading road cuts in Echo Canyon, tah, and borrow pits near Kemmerer, Wyoming.

Artemisia nova Nelson (black sagebrush)

Black sagebrush is a small, spreading, aromatic shrub 1.5 to 4.5 dm tall with a ull grayish-tomentose vestiture that causes most populations to appear darker than ig sagebrush and low sagebrush (fig. 16). However, some forms may be as light in olor as *A. tridentata* or *A. arbuscula* (Beetle 1960). Numerous erect branches arise rom a spreading base, but this shrub had not been observed to layer or stump sprout Beetle 1960). However, we noted some layering of black sagebrush on a roadcut near olob Reservoir, Washington Co., Utah.

Typical leaves are evergreen, cuneate, viscid from a glandular pubescence, 0.5 to cm long, 2 to 8 mm wide, and 3-toothed at the apex (fig. 5c). The uppermost leaves, articularly on the flowering stems, may be entire.

Flower heads are grouped into tall, narrow, spikelike panicles that extend above he herbage (figs. 5c, 16, 17). The inflorescence stalks are red-brown and persistent. he heads usually contain from 3 to 5 disc flowers with corollas 1.8 to 3 mm long. he 8 to 12 involucral bracts are greenish-yellow and nearly glabrous.

*Figure 16.--Four-year-old transplants of black sagebrush (*A. nova*), left, and basin big sagebrush (*A. tridentata ssp. tridentata*), right. Specimens growing at a adaptation plot near Ephraim, Sanpete Co.,*

The principal difference between black sagebrush and low sagebrush is that low sagebrush has 5 to 11 flowers per head, 10 to 15 canescent involucral bracts, and is light in color. Black sagebrush has fewer flowers per head (3 to 5), 8 to 12 glabrous involucral bracts, and is usually darker in color. Also, the flower stalks of black sagebrush are denser, much darker, and more persistent than those of low sagebrush (Ward 1953).

Black sagebrush flowers from August to mid-September, and seeds mature in October and November. Cleaned seed averages 2,000 per gram (907,000 per pound) (Plummer and others 1968).

Insect galls are numerous on this species, but rust diseases are less common (Beetle 1960).

Hybridization.--Both diploid ($2n$ = 18) and tetraploid ($2n$ = 36) forms of black sagebrush have been found (Ward 1953; McArthur and Plummer 1978). Beetle (1960) has found evidence of *A. nova* hybridizing with *A. bigelovii*, *A. tridentata* ssp. *tridentata* and *A. tridentata* ssp. *vaseyana*. Crossing between black sagebrush and basin big sagebrush is fairly common wherever they occur together. The cross with mountain big

*Figure 17.--Black sagebrush (*A. nova*) growing in shallow, stony soil at Clay Hills Mesa, San Juan Co., Utah.*

sagebrush is much less common and occurs only at scattered locations. This is as expected because black sagebrush is commonly associated with basin big sagebrush but only occasionally with mountain big sagebrush.

Although black sagebrush is treated in this paper as a separate species, as was done by Beetle (1960), some authorities consider both black and low sagebrush to be subspecies of big sagebrush (Hall and Clements 1923; Davis 1952; Harrington 1954), while Ward (1953) considers black sagebrush to be a subspecies of *A. arbuscula*. The indication that both black sagebrush and low sagebrush can apparently hybridize with big sagebrush indicates a close affinity of these members of section *Tridentatae*.

Distribution and habitat.--Black sagebrush covers approximately 11,220,000 hectares (43,301 square miles) in the 11 western States (Beetle 1960). It is most abundant at elevations from 1,500 to 2,400 meters (4,900 to 7,900 feet) and normally grows on drier, more shallow stony soil than basin or mountain big sagebrush (fig. 17) (Beatley 1976). Type locality is listed as "Medicine Bow, Carbon County, Wyoming" (Abrams and Ferris 1960).

Use.--Black sagebrush is generally considered highly palatable especially to sheep, goats, antelope, and sage grouse. It is held in high regard as browse for sheep, goats, deer, and antelope on winter ranges in Utah, Colorado, and New Mexico. In some areas it is browsed by cattle, but cattle show less preference for it than other animals. Palatability seems to vary with color. In Nevada, a gray-green form is heavily grazed; whereas, a darker glossy-green form is much less grazed (Brunner 1972). That palatability varies with color forms has been supported by some of our work (Stevens and McArthur 1974).

Black sagebrush is an aggressive natural spreader from seed and provides good ground cover for stabilizing soil. Under proper management, stands depleted by heavy grazing recover within less than 10 years. Some large areas in Nevada formerly occupied by black sagebrush have been invaded by Utah juniper (*Juniperus osteosperma*) and single leaf pinyon pine (*Pinus monophylla*).

Artemisia pygemaea Gray (pigmy sagebrush)

Pigmy sagebrush is a dwarf, depressed, evergreen, cushionlike shrub less than 2 dm tall (fig. 18). Bark on older stems becomes dark brown and fibrous. On young branches the bark is nearly white to straw-colored and somewhat puberulent.

Figure 18.--Pigmy sagebrush (A. pygmaea) growing at the Snow Field Station.

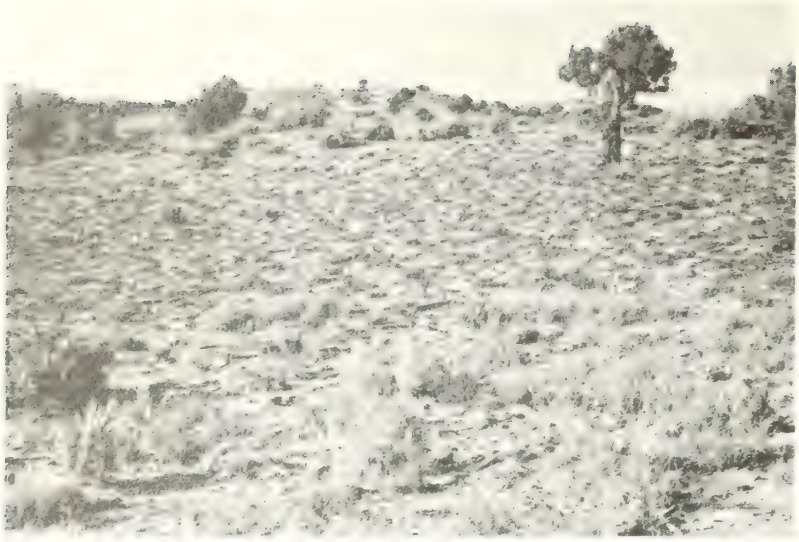


Figure 19.--Pigmy sagebrush (A. pygmaea) growing south of Ouray, Uintah Co., Utah.

Leaves on the vegetative stems are green, nearly glabrous, viscidulous, 2 to 4 mm wide, 2 to 8 mm long and are pinnatified with 3 to 11 lobes, or sometimes may be only toothed. Leaves on the flowering branches are usually reduced and may be entire.

Heads with 3 to 5 disc flowers are arranged into spikelike inflorescence. Ray flowers are lacking. Twelve to 18 greenish-yellow bracts subtend each head. Achenes are glabrous. Flowers bloom in August and September, and seed matures in October. Seeds are large for *Artemisia*. Cleaned seed average 970 per gram (440,000 per pound).

Hybridization.--Both diploid ($2n$ = 18) and tetraploid ($2n$ = 36) forms of *A. pygmaea* are known (Ward 1953; McArthur and Pope, data on file at the Shrub Sciences Laboratory, Provo, Utah).

Distribution and habitat.--Pigmy sagebrush is limited to calcareous soils in desert areas over approximately 5,000 hectares (21 square miles) from eastern Utah to western Nevada, and northern Arizona (Ward 1953; Beetle 1960; McArthur and Plummer 1978) (fig. 19). In Nevada, this species is often associated with the halophytic *C. nauseosus* ssp. *consimilis*. Some fairly large stands occur with black sagebrush in Utah. Its type locality is Fish Creek, near Eureka, Nevada.

Use.--Because of its scarcity and small size, this species has little value as browse. It does, however, provide important ground cover in the dry, alkaline areas where little else will grow. It establishes readily by transplanting divided plants. Although it spreads well from naturally dispersed seed, artificial planting of seed has not been successful.

Artemisia rigida (Nutt.) Gray (stiff or scabland sagebrush)

Stiff sagebrush is a low, pungently aromatic shrub with thick, rigid, somewhat brittle branches up to 4 dm high (fig. 20). It is not known to rootsprout or layer. The deciduous, silvery-canescent, spatulate leaves are mostly 1 to 4 cm long and deeply divided into 3 to 5 narrowly linear lobes. Occasionally some leaves are linear and entire (fig. 21).

Inflorescence is a leafy spike with heads sessile or in small clusters in the axils of their subtending leaves, which generally are all longer than the heads (fig. 22a). The campanulate involucre is 4 to 5 mm long with numerous, canescent bracts. Each head consists of 5 to 16 perfect disc flowers. Flowering occurs during September and October; seeds ripen in November. Seeds number 1,210 per gram (550,000 per pound).

Figure 20.--Scabland sagebrush (A. rigida) growing at the Snow Field Station. The ruler is 30 cm long.

Hybridization.--Both diploid ($2n = 18$) and tetraploid [illegible] sagebrush are known (Ward 1953; McArthur and Plummer 1978). This species resembles *A. tripartita* somewhat in its small size, silvery pubescence, and the deeply, narrowly lobed leaves, but may be distinguished by the spikelike inflorescence, large leafy bracts that subtend the heads, and the deciduous leaves.

Distribution.--Stiff sagebrush occurs in dry rocky scablands in the Columbia and Snake River basins and spills over into the northern end of the Great Basin. It grows at elevations from 910 to 1,520 meters (3,000 to 5,000 feet) in Idaho, central and eastern Oregon, and central and eastern Washington. It is adapted to the rocky scablands of these States and fills an ecological niche similar to that of *A. arbuscula* in the areas where it is found (Ward 1953).

Although several authors (Hall and Clements 1923; Davis 1952; Hitchcock and others 1969) include western Montana in the distribution of stiff sagebrush, neither Ward (1953) nor Beetle (1960) do. Ward (1953) claims the report of *A. rigida* from western Montana is probably a result of errors in identification. He identifies the specimens in this area as *A. tripartita*.

Figure 21.--Leaves and branches of scabland sagebrush (A. rigida).

Figure 22.--Artemisia taxa. *(A)* A. rigida, *Edgerton 1-75, LaGrande, Union Co., Oregon (1.4X). (B)* A. tridentata *ssp.* tridentata, *Culture U77, Enterprise, Washington Co., Utah (0.6X). (C)* A. tridentata *ssp.* vaseyana, *McArthur 697, Provo, Utah Co., Utah (0.9X). (D)* A. tridentata *ssp.* wyomingensis, *McArthur and Plummer 394, Big Piney, Sublette Co., Wyoming (0.9X).*

...--Because of its scant foliage and ... value for browse, except for sheep (Hall and ... important cover on the poor, rocky soils where it grows. It appears to have a wider range of adaptation than is indicated by its present natural range of occurrence, thus giving it potential use in reclamation of disturbed sites.

Artemisia rothrockii Gray (timberline sagebrush)

Timberline sagebrush is a consistently low-growing, evergreen, flat-topped shrub from 1 to 8 dm tall (fig. 23). Its appearance in the field closely resembles some forms of mountain big sagebrush. Timberline sagebrush, however, has a more pronounced, consistent tendency to layer and has thicker, darker, more or less viscid leaves, which give the plant a dark green color.

Leaves on the vegetative branches are often 10 mm broad and 3 cm long (Beetle 1960) but range in size from 2 to 51 mm wide and 0.5 to 5 cm long. The lower leaves are mostly broadly cuneate or fan shaped and 3-toothed or lobed (fig. 5d). The upper leaves, however, may be entire and linear to lanceolate or oblanceolate. The foliage emits a mildly aromatic aroma when crushed.

Flower heads occur singly or occasionally 1 to 3, in short interrupted spike or racemelike inflorescences. Each head contains 6 to 16, rarely as many as 20, disc flowers. Ray flowers are lacking. The 10 to 14 involucral bracts are often brown or purplish. Achenes are granuliferous. Flowers bloom during August and September. Seeds mature during September and October. Plantings of this sage in valley lowlands of central Utah have bloomed profusely, but none of the plants produced mature seed.

Hybridization.--Artemisia rothrockii occurs in diploid ($2n = 18$), tetraploid ($2n = 36$), hexaploid ($2n = 54$), and octoploid ($2n = 72$) forms (Ward 1953; McArthur and Plummer 1978). Beetle (1960) suggests this species may be of hybrid origin from *A. cana*, which it resembles in its strong tendency to layer, large heads and conspicuous bracts, and *A. tridentata*, which it resembles in leaf shape, general habit, and habitat. Our discovery (McArthur and Plummer 1978) that at least some Rocky Mountain forms are diploid does not support Beetle's hybrid ancestry contention. However, the diploid Rocky Mountain material may be an undescribed taxon rather than bona fide *A. rothrockii*.

Figure 23.--A row of timberline sagebrush (A. rothrockii) growing at the Snow Field Station, Ephraim, Sanpete Co., Utah.

Figure 24.--Budsage (A. spinescens) growi near Sevier Lakebed, Millard Co., Utah.

Distribution and habitat.--Timberline sagebrush covers approximately 27,200 hectares (103 square miles) at between 2,600 and 3,350 meters (8,500 and 11,000 feet) in elevation in high mountainous areas of central Colorado, western Wyoming, and the central Sierras of California (Beetle 1960). This species is usually found growing in deep soils along the margins of forests. This species, or a similar undescribed form is also found in other western States, particularly in the high mountains of Utah, Id and Nevada. *A. rothrockii's* type locality is the Monache Meadows, 2,600 meters (8,500 feet), Sierra Nevada Mountains, Tulare County, California (Hall and Clements 1923; Beetle 1960).

Use.--Timberline sagebrush is a palatable sagebrush, grazed heavily by big game and livestock. It shows potential as low hedge for landscaping.

Artemisia spinescens Eaton (budsage[4])

Budsage is a low, spinescent, pungently aromatic, rounded shrub 1 to 5 dm high (fig. 24). It is profusely branched from the base and has white-tomentose pubescence on young twigs and leaves. This pubescence is grayish and stiff on older branches.

Leaves are small, mostly 2 cm or less in length, including the petiole. Leaves are 3 to 5 palmately parted, with the divisions again divided into 3 linear-spatulate lobes (fig. 12c). Leaves are crowded on the short stems, with those near the apex being smaller and more entire. Unlike most species of *Artemisia*, budsage is deciduous with the leaves falling by midsummer.

Early in the spring, when budsage first shows signs of breaking dormancy, but before the buds elongate, the bark from the last season's growth can easily be pulled off. At this developmental stage, budsage is sought out by big game and livestock. Sheepmen refer to this condition as "slipping." As early as February or March, new bright-green leaves are produced.

[4]Also called spring sagebrush and bud sagebrush.

Budsage is well adapted to xeric condition[illegible] grows primarily in the top 15 to 55 cm of soil. [illegible] over the last year's wood in both the roots and the stem. This layer of cork restricts the upward movement of water to the very narrow zone of wood formed by the current year's growth. The corky tissue develops during early summer and thus helps to prevent excessive water loss during the dormant season (Wood 1966). Many other xerically adapted woody *Artemisias* also have interxylary cork (Moss 1940).

Budsage bears small flower heads (3 to 5 mm long) in glomerate racemes of 1 to 3 heads in leaf axils of the flower branches. Each head contains 2 to 6 fertile, pistillate ray flowers and 5 to 13 perfect but sterile disc flowers with abortive ovaries.

The loose flower heads are held together by long, matted hairs that cover the corolla and especially the achenes. The heads fall from the plant intact, without breaking apart to release the seed. Seeds germinate in some instances, while still in the head (Wood 1966). Good seed production occurs infrequently. The flowers bloom so early in the spring that developing embryos frequently are frozen. Abundant reproduction occurs in years of plentiful seed and favorable moisture.

Terminal and lateral buds of budsage generally expand and begin to elongate in late March and early April during the latter part of the "slipping" period. Blooming normally occurs from the last week in April through the last week in May, although it has been found in bloom as early as late March and as late as mid-June (Wood 1966). Cleaned seed averages 4,855 per gram (2,200,000 per pound).

Although budsage ordinarily begins growth early in the spring and then becomes dormant by early or midsummer, it occasionally may break dormancy in response to late summer storms. The plants then remain green all winter to provide succulent forage throughout the winter and spring.

As a species, budsage is distinguished by its spinescent habit and low variability in involucre and floral characteristics. The harsh environment in which budsage grows has perhaps helped to stabilize this species so that no variants have yet been recognized and named.

Hybridization.--Artemisia spinescens has chromosome numbers of $2n = 18$ and $2n = 36$ (Powell and others 1974; McArthur and Pope 1977). It is not known to hybridize with any other species. Its tetraploid form is thought to be autotetraploid (McArthur and Pope, data on file at the Shrub Sciences Laboratory, Provo, Utah).

Distribution and habitat.--Budsage is a very drought-resistant shrub found on dry, often saline plains and hills from southwestern Montana, central Idaho, and eastern Oregon southward to southeast California, New Mexico, Arizona, and Colorado. Type locality is "Rocky Mountain plains, in arid deserts, toward the north sources of the Platte" (Abrams and Ferris 1960). It is often associated with shadscale, black greasewood (*Sarcobatus vermiculatus*), and other salt-tolerant shrubs. In some areas, it is associated with black sagebrush and basin big sagebrush.

Use.--Budsage is a palatable, nutritious forage plant for upland birds, small game, big game, and sheep in the winter. Generally, it is more palatable in the late winter than during the early winter (Holmgren and Hutchings 1972). During this time it is of tremendous value to the welfare of grazing animals, especially where there is an abundance of dry grass.

Care must be taken in grazing budsage in late winter and early spring. Even light grazing during this period is detrimental, and continual, heavy grazing may eliminate budsage from the area (Holmgren and Hutchings 1972).

*Figure 25.--Large specimen of basin big sagebrush (*A. tridentata *ssp.* tridentata*) growing near LaSal, San Juan Co., Utah.*

Artemisia tridentata Nutt. (big sagebrush[5])

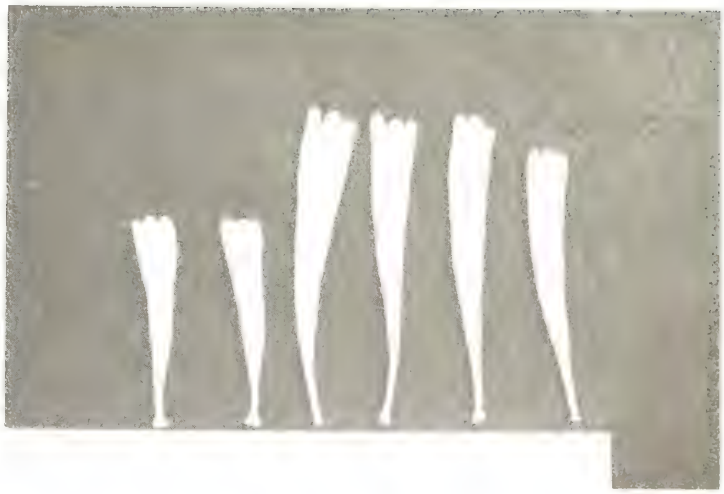
Big sagebrush is a highly polymorphic species with numerous ecotypes and biotypes. Three subspecies (*tridentata*, *wyomingensis*, and *vaseyana*) are generally recognized at the present time (Beetle 1960; Beetle and Young 1965), and will be discussed individually following the general presentation of the species.

Big sagebrush is composed of aromatic, evergreen shrubs ranging in size from dwarf to tall, arborescent forms up to 4.5 m tall (fig. 25). The lower forms generally have several main stems arising from the base, whereas the tall forms often have a single short trunk. Older branches are covered with a gray to brown or black shredded bark. Younger branches and leaves have a white to gray tomentum which gives the plants a silvery cast.

Typical leaves are narrowly cuneate or oblanceolate and terminate with 3 blunt teeth at their truncate apexes (fig. 26). However, considerable variation occurs, ranging from linear, entire leaves with rounded to acute apexes to broadly cuneate leaves with varying number of teeth or shallow lobes. The leaves also range in size from 2 mm to 2 cm broad and 1 cm to 6.5 cm long. Normally, leaves on vegetative shoots are more characteristic and less variable than those on flowering shoots. Also, persistent leaves, that is overwintering leaves, are less variable than leaves of the spring growth flush (Winward 1970), which are shed by midsummer.

[5]Other common names include common sagebrush and black sage.

Figure 26.--Typical leaves of basin big sagebrush (A. tridentata ssp. tridentata). Bar scale is in mm.



Heads of this species contain 3 to 8 disc flowers each and are arranged into leafy panicles with erect or sometimes drooping branches. In some forms, the inflorescence becomes spikate. Blooming occurs from July to October. Seeds (fig. 27) mature in October, November, and December. There are about 5,510 seeds per gram (2,500,000 per pound) (Plummer and others 1968; Deitschman 1974). Big sagebrush plants often live 100 years. Specimens from several sites were found to be more than 200 years old (Ferguson 1964).

Hybridization.--Artemisia tridentata has a basic chromosome number of $x = 9$. Both diploid ($2n = 18$) and tetraploid ($2n = 36$) forms are known (Ward 1953; Taylor and others 1964; Winward 1970; Kelsey and others 1975; McArthur and Plummer 1978; McArthur and Pope, data on file at the Shrub Sciences Laboratory, Provo, Utah). In many cases there is no morphological difference between the diploid and tetraploid plants. In fact they may grow together. Subspecies *tridentata* and *vaseyana* both have diploid, tetraploid, and mixed populations. Subspecies *wyomingensis* is now known only as a tetraploid.

This species readily crosses both intraspecifically and interspecifically (table 2). In their chromatographic work, Hanks and others (1973) found evidence of natural hybridization among the following species and subspecies: *A. tridentata* ssp. *vaseyana* with *A. tridentata* ssp. *tridentata*, *A. arbuscula* ssp. *arbuscula*, *A. nova*, *A. tripartita*

Figure 27.--Basin big sagebrush (A. tridentata ssp. tridentata) seed (7X).

Treatment	Seed produced								
	1974			1975			1976		
	N	$\bar{X} \pm se^2$	Range	N	$\bar{X} \pm se^2$	Range	N	$\bar{X} \pm se^2$	Range
Open pollination	26	1,222±199*	11-3,000	16	1,845±345*	10-4,000	42	1,575±322*	0->5,000
Intrapopulation	25	115±40	0-1,000	26	11±5	0-100	41	77±21	0-500
Interpopulation Bag 1	25	78±24	0-300	14	16±7	0-94	39	31±10	0-250
Interpopulation Bag 2	26	62±14	0-300	14	14±7	0-100	40	24±9	0-300
Control	26	37±12	0-300	10	10±3	0-30	42	12±5	0-200

[1]Taxa involved in hybridization experiments include *A. arbuscula*, *A. bigelovii*, *A. cana*, ssp. *viscidula*, *A. nova*, *A. pygmaea*, *A. tridentata* ssp. *tridentata*, *A. t.* ssp. *vaseyana*, *A. t.* ssp. *wyomingensis*, and *A. tripartita* ssp. *tripartita*.

[2]The * in the $\bar{X}$ (mean) ± se (standard error of the mean) column indicates a significant difference in the open pollination treatment from all other treatments. None of the other treatments were significantly different, according to the multiple range test ($p<.05$).

ssp. *tripartita*, and *A. cana* ssp. *viscidula*; *A. tridentata* ssp. *tridentata* with *A. tripartita* ssp. *tripartita* and *A. tridentata* ssp. *wyomingensis*. Beetle (1960) reported finding intermediates between the following: *A. tridentata* ssp. *tridentata* with *A. tridentata* ssp. *vaseyana*, and *A. cana* ssp. *cana* with *A. nova*.

Ward (1953) examined two mixed populations of *A. tridentata* and *A. cana*. In one population the *A. tridentata* was diploid and the *A. cana* was tetraploid. In the other population, *A. tridentata* was tetraploid while the *A. cana* was diploid. The putative hybrids from both populations were tetraploid and blended in with the tetraploid parent.

Because of its plasticity and the apparent ease with which it hybridizes, there are great opportunities for developing improved forms of big sagebrush for different purposes. Controlling the hybridization, however, may prove very difficult.

Distribution and habitat.--Big sagebrush is the most widespread and common shrub of western North America. It is especially common in the Great Basin. This species covers approximately 58,655,000 hectares (226,374 square miles) in the 11 western States (Beetle 1960). It grows in a variety of soils on arid plains, valleys, and foothills to mountain slopes from 500 to 3,400 meters (1,600 to 11,200 feet) and is frequently associated with such shrubs as shadscale saltbush, rubber rabbitbrush, low rabbitbrush, fourwing saltbush, spiny hopsage (*Grayia spinosa*), spiny horsebrush (*Tetradymia spinosa*), winterfat, and broom snakeweed.

Although it is tolerant of quite alkaline as well as quite acid soils, its optimum growth is in deep, fertile, alluvial loams (Sampson and Jesperson 1963).

Although big sagebrush has spread with settlement of the West (Cottam 1961; Christensen and Johnson 1964; Hull and Hull 1974), nevertheless, it was clearly an important and widespread plant before this settlement. As early as the Pleistocene Epoch, sagebrush was already an important part of the Intermountain Flora. Eight to ten thousand years ago, sagebrush dominated large tracts of land in areas where it is still found (Tidwell and others 1972; Van Devender 1977). Vale (1975), quoting from early pioneer and explorer diaries, has shown it was a common western plant prior to 1850.

Big sagebrush and its section *Tridentatae* relatives (table 1) are subject to insect and microbial pests and benefactors--most notably, the sagebrush defoliator moth (*Aroga websteri*). Wide ranging and periodic outbreaks of this insect have caused extensive sagebrush mortality over much of the range of *A. tridentata* and its relatives (Henry 1961; Hall 1965; and personal observations of the authors). However, except on some

*Figure 28.--Basin big sagebrush (*A. tridentata *ssp.* tridentata*) growing with crested wheatgrass (*Agropyron cristatum*) in Pigeon Hollow, Sanpete Co., Utah.*

critical winter game ranges, *Aroga websteri* is not believed to have serious, long-term effects. The moth is subject to insect parasites and predators and does not completely kill off sagebrush stands (Hall 1965). In time sagebrush naturally reinvades its old sites which in the mean time have become more diverse plant communities. During drought periods grasshoppers have been known to defoliate *A. tridentata* (E. F. Schlatterer, letter 12/1/77). Galls of many kinds of flies (Diptera) are found on sagebrush (Hall 1965; Jones 1971; C. F. Tiernan, data on file at the Shrub Sciences Laboratory, Provo, Utah). The effect of the galls is not known. Sagebrush hosts many other insects of various orders. Some of these may protect the plant from disease vectors. Several microbial-induced diseases are known (Krebill 1972). Some of these are widespread and may be locally destructive; however, sagebrush populations are resilient and generally are not significantly affected in the long run. D. L. Nelson (data on file at the Shrub Sciences Laboratory, Provo, Utah) has recently isolated several fungal species of the genera *Verticillium*, *Fusarium*, and *Rhizoctonia* from dying sagebrush in uniform gardens. We have observed similar symptoms (dying desiccated plants) in natural populations. We believe diseases induced by these fungi may be among the most serious sagebrush diseases. Some microbes are likely useful for the vigor and growth of sagebrush. Wallace and Romney (1972) found preliminary evidence that *A. tridentata* formed symbiotic relationships with microbial endophytes to fix atmospheric nitrogen. Williams and Aldon (1976) found endomycorrhizae within *A. tridentata* roots and abundant spores around the roots. Endomycorrhizae, in general, have a beneficial influence on plant growth by promoting nutrient absorption through infected roots (Williams and Aldon 1976). For sagebrush, the beneficial effect is suggestive but not yet proven.

Use.--Artemisia tridentata is one of the more nutritious shrubs on western winter livestock and game ranges. Subspecies *tridentata* has higher protein levels than the other two subspecies (Welch and others 1977). Unfortunately, this species also contains considerable aromatic oil, which may reduce its digestibility (Nagy and others 1964). Nevertheless, because of its widespread abundance, its ability to grow with associated grasses (figs. 4, 28), forbs, and other shrubs and its nutritious nature, big sagebrush is the most important winter forage in foothill areas through much of the West for livestock and big game. Furthermore, the volatile oil content varies with subspecies and accession (Sheehy and Winward 1976; Scholl and others 1977; Welch and McArthur, data on file at the Shrub Sciences Laboratory, Provo, Utah). Perhaps the oil content could be reduced in improved planting stock. It is one of the best shrubs available for use in revegetation of depleted winter game ranges in the Intermountain area (fig. 29) (Plummer 1974).

*Figure 29.--Basin big sagebrush (*A. tridentata *ssp.* tridentata*) that has been seeded after juniper-pinyon control near Fillmore Millard Co., Utah.*

Palatability of the different populations of this shrub varies widely. Basin big sagebrush (*A. tridentata* ssp. *tridentata*) is generally less palatable than Wyoming big sagebrush (*A. tridentata* ssp *wyomingensis*); both are less palatable than mountain big sagebrush (Hanks and others 1973; Sheehy and Winward 1976). Hanks and others (1973) found that intermediates exhibit considerable variation in their palatability, but are usually preferred to plants of the subspecies *tridentata*. Sagebrush is important food and cover for upland birds. For example, sagebrush was found to comprise 62 percent of the annual diet of sage grouse in Montana (Wallestad and others 1975). Big sagebrush is an important component of antelope diet. Olsen and Hansen (1977) found sagebrush comprised 78 percent of the annual diet for antelope in Wyoming's Red Desert.

Big sagebrush stands are unexcelled in providing ground cover and forage when grazed to maintain a balance between the sagebrush and associated herbs and shrubs (Plummer and others 1968). Because big sagebrush establishes rapidly from both transplanting and direct seeding, it is useful for stabilizing washes, gullies, roadcuts, and other raw, exposed sites.

In the Old West, big sagebrush was commonly used by both Indians and the white settlers for fuel and for construction of shelters. Its wood makes a quick, hot fire, and its branches thatched temporary homes and sheds (Hall and Clements 1923).

Subspecies.--Artemisia tridentata ssp. *tridentata* (basin big sagebrush[6]) is an erect, heavily branched, unevenly topped shrub. This subspecies has undivided, or at least trunklike, main stems. Shrubs range between 1 and 2 meters in height (fig. 30). Some forms, however, may reach 4.5 meters in suitable habitats (fig. 25). Mature shrubs of this subspecies are the largest members of the big sagebrush complex. The evergreen, vegetative leaves are narrowly lanceolate, up to 5 cm long by 5 mm wide, and typically 3-toothed at the apex (fig. 22). The leaves of the flowering stems, however, gradually become smaller and may be linear or oblanceolate and entire. Winward (1970) found the average length-to-width ratio of persistent leaves on specimens from Idaho to be 5.6. The gray-canescent foliage possesses a strongly pungent, aromatic odor. Flowering stems arise throughout the uneven crown and bear numerous flower heads in erect, leafy

[6]Other common names include common sagebrush, common big sagebrush, narrowleaf big sagebrush, and valley big sagebrush.

Figure 1.--Two basin big sagebrush plants representing the range of variation in the big sagebrush A. tridentata ssp. tridentata. The form on the left was transplanted from Jackson Mountains, Humboldt Co., Nevada; the one on the right was transplanted from the Jackson Mountains, Humboldt Co., Nevada. The plant in the center is a Wyoming big sagebrush.

panicles. The heads contain 3 to 6 small yellowish or brownish, trumpet-shaped, perfect-disc flowers. The narrowly campanulate involucre consists of canescent bracts 3 to 4 mm long and about 2 mm wide that form 4 to 5 overlapping series around each head. The outermost bracts are less than a fourth as long as the innermost bracts. Flowering occurs from late August to October. Seed matures depending on site from October to November. Basin big sagebrush is probably the most abundant shrub in western North America on lowland ranges. It normally occurs on dry, deep, well-drained soils on plains, valleys, and foothills below 2,130 meters (7,000 feet) elevation. Above this elevation, subspecies *vaseyana* and occasionally subspecies *wyomingensis* are more prevalent. Vigorously growing basin big sagebrush is considered indicative of productive ranges because it often grows in deep, fertile soil. This subspecies has generally been regarded as intolerant of alkali, but there are ecotypes that grow in relatively high alkalinity in association with such alkali-tolerant plants as black greasewood, shadscale saltbush, and saltgrass (*Distichlis stricta*). Plants with strikingly reflexed drooping branches of inflorescence are found throughout the range of subspecies *tridentata*. These have been termed *A. tridentata* ssp. *tridentata* f. *parishii* (Beetle 1959). This form may be environmentally induced because some ssp. *vaseyana* populations of central Nevada also have drooping inflorescences in some years (E. F. Schlatterer, letter 12/1/77).

Artemisia tridentata ssp. *vaseyana* (mountain big sagebrush) is normally a smaller shrub than basin big sagebrush. Its main stem is usually divided at or near the ground, and it tends to have a spreading, evenly topped crown (fig. 31). The vegetative branches are usually less than 1 meter high and frequently layer at their bases. There are, however, ecotypes at lower elevations that may reach about 2 meters in height. The persistent vegetative leaves are broadly cuneate to spatulate and are characteristically wider than those of both basin and Wyoming big sagebrush (fig. 22c). When looking down at this shrub, the terminal leaves on each twig appear to be distinctly whorled (fig. 32). Subspecies *tridentata* does not show this trait. However, ssp. *wyomingensis* shows the trait to some extent. Normally, the leaves are 2 cm long, 5 mm broad, but in form *spiciformis* may reach 6.5 cm long and 2 cm broad. Leaf length-to-width rates for typical persistent *vaseyana* leaves average 4.0 while that of form *spiciformis* averages 3.5 (Winward 1970). Crushed leaves emit a rather pleasant mintlike fragrance in contrast to the more pungent odor of both basin and Wyoming big sagebrush. Flower heads are arranged into narrow, often dense panicles or spikes. The heads contain 5 to 8 trumpet-shaped, perfect-disc flowers. The broadly campanulate involucre consists of numerous canescent overlapping bracts, 5 mm long and 3 to 4 mm wide. The outermost bracts are less than half as long as the innermost. Some strains of mountain big sagebrush start blooming as early as July and thus may be in bloom up to 6 weeks earlier than either basin or Wyoming big sagebrush (Hanks and others 1973). Seed

*Figure 31.--An even-topped mountain big sagebrush (*A. triden-tata *ssp.* vaseyana*) growing in the Targh National Forest, Sub-lette Co., Wyoming.*

*Figure 32.--Big sagebrush leaves seen from above. Specimens growing at the Snow Field Station. (A) The whorled terminal leaves of mountain big sagebrush (*A. tridentata *ssp.* vaseyana*) transplanted specimen from Ephraim Canyon, Sanpete Co., Utah. (B) The contrasting nonwhorled appearance of basin big sagebrush (*A. tridentata *ssp.* tridentata*) transplanted from Dog Valley, Juab Co., Utah.*

Figure 22.--Wyoming big sagebrush (A. tridentata ssp. wyomingensis) growing near Daniel, Sublette Co., Wyoming.

matures from September through October. In the Intermountain West, mountain big sagebrush occurs in the upper elevational range of the big sagebrush zone in deep, well-drained soils on mountain slopes from below 1,400 meters (4,600 feet) for f. *xericensis* and at elevations over 3,000 meters (9,800 feet) for f. *spiciformis* (Beetle and Young 1965; Winward 1970). The form *xericensis* is unevenly topped and grows in relatively dry sites similar to basin and Wyoming big sagebrush. In Idaho, this form is known to occur between 780 to 1,400 meters (2,600 to 4,600 feet). Chromatographically, cytologically, and phenologically, *xericensis* most closely resembles and is considered to be a form of ssp. *vaseyana* (Winward 1970; Hanks and others 1973; Winward and Tisdale 1977). The form epithet "*xericensis*" has not been validly published. Winward (1970) used the term. Later, he and Tisdale (1977) merely called this "X big sagebrush." Hanks and others (1973) used an analogous term, low elevation *vaseyana*. Form *spiciformis* has larger flower heads and leaves than typical *vaseyana* and is found at higher elevations, usually over 2,130 meters (7,000 feet) in the cooler, more mesic sites. *Vaseyana* grows in slightly acid to slightly alkaline soils (Welch and McArthur, data on file at Shrub Sciences Laboratory, Provo, Utah). Unlike ssp. *tridentata*, *vaseyana* is rarely associated with any of the saltbushes.

Artemisia tridentata ssp. *wyomingensis* (Wyoming big sagebrush) is somewhat intermediate in distribution, ecology, and morphology between basin big sagebrush and mountain big sagebrush. Occasionally, all three subspecies may be found growing together. Whenever it is found associated with ssp. *tridentata*, ssp. *wyomingensis* is growing in the poorer, more shallow soils (Beetle and Young 1965). Subspecies *wyomingensis* is a low shrub usually less than 1 meter in height. It has an uneven top with flower stalks arising throughout the crown like ssp. *tridentata* (fig. 33). Its main stems branch at or near the ground level like ssp. *vaseyana*, but it does not layer. Leaves are 1 to 2 cm long, narrowly cuneate to cuneate (fig. 22d), and have an average length-to-width ratio of about 3:1 for the persistent leaves (Winward 1970). Flower heads contain 3 to 8 disc flowers and are arranged into panicles narrower than the paniculate inflorescence of *tridentata* and wider than the spicate inflorescence of *vaseyana* (Beetle and Young 1965; Winward and Tisdale 1977). Flowering and seed ripening take place later than *vaseyana* and earlier than *tridentata*. This subspecies may have arisen from hybridization between ssp. *tridentata* and *vaseyana* (Hanks and others 1973) or ssp. *tridentata* and *A. nova* (Winward 1975). Wyoming big sagebrush grows throughout the Intermountain region (fig. 34). It is particularly abundant east of the Continental Divide in Montana, Wyoming, and parts of Colorado in dry, shallow, gravelly soil, usually from 1,500 to 2,100 meters (5,000 to 7,000 feet) (Beetle and Young 1965). In Idaho, this subspecies is found from 760 to 1,980 meters (2,500 to 6,500 feet) in the hotter, drier portions of the State (Winward 1970).

Figure 34.--A large stand of Wyoming big sagebrush (A. tridentata ssp. wyomingensis growing near its type locatio Daniel, Sublette Co., Wyoming Note size contrast to basin big sagebrush of figure 25.

Artemisia tripartita Rydb. (threetip sagebrush)

Threetip sagebrush is a rounded, evergreen shrub up to 2 meters high. It may have a simple, trunklike main stem or several branches arising from the base. The bark on young branches is canescent, but becomes shredded and grayish, light brown to dark brown or black on older stems. This species can layer, sometimes sprouts back after a burn, and may sprout from the stump following herbicide treatments (Beetle 1960; Pechanec and others 1965; Schlatterer 1973).

Leaves of the vegetative branches are canescent, 0.5 to 4 cm long, and typically deeply divided into 3 linear or narrowly linear-lanceolate lobes (fig. 12d), which in turn may be 3-cleft. Some of the upper leaves are often entire. Crushed foliage emits a pungent odor.

Flower heads contain 3 to 11 disc flowers and are normally arranged into panicles. Ray flowers are lacking. Each head is subtended by 8 to 12 canescent involucral bracts Achenes are resinous-granuliferous. Blooming occurs from July to September. Cleaned seeds average 5,490 per gram (2,490,000 per pound).

Hybridization.--*Artemisia tripartita* occurs in both diploid ($2n$ = 18) and tetraploid ($2n$ = 36) forms (Ward 1953; McArthur and Pope, data on file at the Shrub Sciences Laboratory, Provo, Utah). Some evidence of natural hybridization involving this specie and other shrubby *Artemisia* has been found (Beetle 1960; Hanks and others 1973).

Distribution and habitat.--Threetip sagebrush covers approximately 3,370,000 hectares (13,002 square miles) in the Northern Rocky Mountains and Great Basin States from British Columbia south through Montana and Wyoming to Colorado and west to Washington, Oregon, northern Nevada, and northern Utah at elevations between 900 to 2,750 meters (3,000 to 9,000 feet) (Beetle 1960). In some places, particularly in Idaho, this species occurs between the lower, hot, dry sites dominated by Wyoming big sagebrush and the higher, cooler sites dominated by mountain big sagebrush (Schlatterer 1973).

Use.--Threetip sagebrush is a vigorous seeder, but unfortunately some forms are not particularly palatable. Beetle (1960) reported it was of low palatability for both livestock and game, and Brunner (1972) observed that it was never grazed in

Nevada. However, a form near Salmon, Idaho, is palatable to deer. The form near Salmon is intermediate in morphology between *A. tripartita* and *A. tridentata* spp. *wyomingensis* (E. F. Schlatterer, letter 12/1/77).

Subspecies.--Artemisia tripartita ssp. *rupicola* (Wyoming threetip sagebrush) is a dwarf shrub with decumbent branches that rarely grow over 1.5 dm tall. It is frequently found layering and may have a crown spread of 3 to 5 dm (Beetle 1960). Leaves of the vegetative branches are often 3 cm long and deeply divided into linear lobes, each at least 1 mm wide (Beetle 1959, 1960). Flower heads bear 3 to 11 disc flowers and are arranged into leafy, narrowly racemose panicles. Flowers bloom in late August and September. Seed ripens in October. Wyoming threetip sagebrush has a rather limited range. It occurs on rocky knolls from 2,430 to 2,740 meters (7,000 to 9,000 feet) in elevation in central and southeast Wyoming (Beetle 1960). Brunner (1972) reported this subspecies also occurs in southern Oregon but has not yet been found in Nevada. It typically grows on sites adjacent to those of mountain big sagebrush.

Artemisia tripartita ssp. *tripartita* (tall threetip sagebrush) is a freely branching shrub up to 2 meters high. It can layer easily when the conditions are right, but is seldom found layering in the field. After burning, it may stump-sprout (Beetle 1960). Leaves of the vegetative branches are 1.5 to 4 cm long and deeply divided into 3 linear lobes less than 1 mm wide. The lobes may be further divided (Beetle 1959, 1960). Flower heads bear 4 to 8 disc flowers and are arranged into panicles that may sometimes be reduced to a spicate form. Flowers bloom in late August and September. Seeds ripen in October. This subspecies occurs in dry, well-drained soils at 900 to 2,300 meters (3,000 to 7,500 feet) elevation from British Columbia south through Washington to northern Nevada and eastward to northern Utah and western Montana. Its type locality is listed as "Plains of Rocky Mountains" (Beetle 1960).

Artificial hybridization in section *Tridentatae* of *Artemisia*

Our experiments in hybridizing *Artemisia* section *Tridentatae* were undertaken with plant improvement in mind (McArthur and Plummer 1974; McArthur and Pope 1975). The section contains many taxa with different combinations of traits. We think some of these traits such as growth form, palatability, adaptation, protein and volatile oil content, and vegetative spread might be brought together in various combinations for the land manager's benefit.

The experiments were designed to determine: (1) Does hybridization occur and if so (2) can it be controlled, and (3) to what extent are section *Tridentatae* plants self-fertile? These questions are, of course, all interrelated. We have referred to evidence for hybridization under each species that has been discussed. This evidence is in the form of morphological and chemical intermediates. More definite evidence is available. We have found triploid and pentaploid seedlings at the Snow Field Station (McArthur and Pope, data on file at the Shrub Sciences Laboratory, Provo, Utah). The best explanation for their occurrence is that plants of different polyploid levels hybridized. The *Tridentatae* are mostly wind pollinated, a condition that gives opportunity for hybridization. Estes (1968) presented solid cytological, morphological, and pollen stainability (an indication of pollen viability) data for hybridization in the *A. ludoviciana* complex. Estes' (1968) hybrids included some interspecific hybrids. On the other hand, Persson (1974) produced intraspecific hybrids in the *A. maritima* complex, but she was not able to produce any interspecific hybrids.

Controlled hybridization of sagebrush (section *Tridentatae*) is no easy matter. The small perfect flowers are impossible to hand emasculate. Our attempts to induce male sterility by using hot water and the ethelyne analog, Ethrel®, were not successful. The hot water treatment at 40° and 45°C for 2, 5, and 10 minutes stopped all seed development when applied just prior to flower head opening. Higher water temperatures

(50 C) killed the plant tissues. Our experiments at inducing male sterility with Ethrel® failed to uncover any differential action on pollen and ovule formation such as occur on wheat and other grasses (Rowell and Miller 1971). Our experiments with more conventional techniques; namely, mass pollination, were more successful, but the results were not definitive (see table 2, page 28).

The *Tridentatae* do not appear to be self-sterile (table 2). Seed was set in the unopened control bags. We cannot make the case for self-compatibility point as strongly as we would like to, however, because the pollination bags sift small amounts of pollen. The bakery bags sifted no more pollen than commercial paper and woven cloth bags prepared specifically for hybridization experiments. We (McArthur and Blauer, data on file at the Shrub Sciences Laboratory, Provo, Utah) found only minimal amounts of pollen on petroleum-coated microscope slides inside of the control bags. These tests were made primarily with *Atriplex* pollen but also with *Artemisia* pollen and unidentified pollen. Pollen does not sift into the bags in quantity enough to produce seed sets of up to 300 seeds per pollination bag (table 2). Apparently, therefore, selfing occurs.

We believe, above and beyond the background of selfing, hybrid seed is also set. Our 3 years' data (table 2) show a trend for higher interpopulation and intrapopulation seed set than seed set in the control bags (selfing and sifting). The differences are not significant, perhaps because of the wide variations in seed set in the bags. The environment within the bags was not natural. When the bags were opened, some enclosed branches were drier and some more moist than adjoining unbagged branches.

CHARACTERISTICS OF THE GENUS *CHRYSOTHAMNUS* (RABBITBRUSH)

This genus consists of much-branched subshrubs or shrubs up to 3 m high with ascending to erect stems bearing alternate, narrow, deciduous leaves. The herbage ranges from glabrous to densely tomentose and is commonly resinous and aromatic.

Rabbitbrush flowers are borne in heads that in turn are arranged into cymes, racemes, or panicles (fig. 35). The heads usually contain from 5 to 15 yellow or sometimes white disc flowers and are subtended by involucral bracts (fig. 36) arranged into 5 more or less distinct vertical ranks. Each flower contains a pappus of abundant, white, slender capillary bristles (fig. 37), a 5-toothed or cleft tubular to funnelform corolla, 5 stamens united by their anthers around the style, and a pistil with

*Figure 35.--The inflorescence of Howard rabbitbrush (*C. parryi *ssp.* howardi*). Plant growing at Current Creek, Duchesne Co., Utah.*

Figure 18.--Leaf morphology of Chrysothamnus (12X). (A) C. nauseosus ssp. albicaulis with acutely angled tips. Specimen from Levan, Juab Co., Utah (McArthur and Blauer N-18).

(B) C. nauseosus ssp. salicifolius with obtusely angled tips. Specimen from Strawberry Valley, Wasatch Co., Utah (Tiernan s.n.).

(C) C. parryi ssp. attenuatus with long, attenuate tips (arrow). Specimen from Salina Canyon, Sevier Co., Utah (McArthur and Blauer SC 74-40). Note pappus (a), corrola (b), and stigma (c).

*Figure 37.--Pappus on developing achene of mountain rubber rabbitbrush (*C. nauseosus *ssp.* salicifolius*). Specimen from Ephraim Canyon, Sanpete Co., Utah (7X).*

two exserted stigmas (fig. 38) and an ovary that develops into a 1-seeded glabrous to densely pubescent achene. The basic chromosome number for rabbitbrush is $x = 9$. Polyploidy is limited in the genus, having been found in only a few subspecies of *C. viscidiflorus* (Anderson 1971).

The rabbitbrushes are endemic to western North America in open plains, valleys, foo hills, and mountains from sea level to 3,300 meters (10,900 feet) in elevation (Hitchcock and others 1969; USDA Forest Service 1974). In addition to their importance as browse and soil stabilizers, rabbitbrushs are used by the Hopi Indians for making windbreaks, arrows, wickerwork, and as fuel in their ceremonial chambers (kivas). Flowers and inner bark may be used to make yellow and green dye, respectively (Kearney and Peebl 1960). Rabbitbrushes, particularly the larger ones, provide late-season nectar that pro duces a dark, strong-flavored honey (D. T. Booth, letter 11/16/77). The dark color and late nectar flow (coming after most sources have ceased) make rabbitbrush especially valuable in winter beehives.

Besides the eight species (*C. albidus, C. depressus, C. greenei, C. linifolius, C. nauseosus, C. parryi, C. vaseyi,* and *C. viscidiflorus)* treated in the publication, there are a few other *Chrysothamnus* species. Some, for example, *C. pulchellus* do not occur in

*Figure 38.--Flower head of mountain rubber rabbitbrush (*C. nauseosus *ssp.* salicifolius*. Specimen from Ephraim Canyon, Sanpete Co., Utah (7X).*

the Intermountain area; others, such as *C. paniculatus* and *C. teretifolius*, occur in portions of the Intermountain area but are only minor constituents of the flora.

Chrysothamnus albidus (Jones) Greene (alkali or white flowered rabbitbrush)

Alkali rabbitbrush is a much-branched, leafy shrub. It has erect, brittle, glabrous, very resinous, white-barked branches up to 1 meter high (fig. 39a). The glabrous, filiform leaves are 1.5 to 4 cm long, 0.5 to 2 mm wide, and the margins become revolute. Their surface is covered with small pits and abundant resinous exudate.

Heads with 4 to 6 white disc flowers each are arranged in small compact cymes. Each head is subtended by approximately 15 glabrous, resinous, involucral bracts. These are 7 to 9 mm long and terminate in attenuate to acuminate, usually curved tips. The pappus is abundant and longer than the corollas. Mature achenes are about 4 mm long and densely covered with long soft hairs. Blooming occurs from August to November.

Hybridization.--Chrysothamnus albidus has a chromosome number of $2n = 18$ (Anderson 1966, 1971; Anderson and others 1974). Only diploid individuals have been found in this species. Hybridization between this species and at least *C. nauseosus* appears possible. Anderson (1970) has obtained seed from *C. albidus* that produced plants somewhat intermediate between the putative parents.

Perhaps greater alkalinity tolerance could be bred into the more palatable forms of rubber rabbitbrush by crossing them with alkali rabbitbrush. These forms could then be used to increase palatable forage as well as ground cover in sparsely vegetated alkaline areas.

Distribution and habitat.--This species is a definite halophyte. It occurs most commonly along the western side of the Great Salt Lake desert, but is also found across Nevada to eastern central California in alkaline soils. Alkali rabbitbrush may invade strongly alkaline areas as a pioneer plant. In less alkaline flats it may be associated with threadleaf rubber rabbitbrush, giant wildrye, and greasewood. Its type locality is listed as "alkaline soil, Wells, Nevada" (Hall and Clements 1923).

Use.--This species has value as ground cover on alkaline soils.

Chrysothamnus depressus Nutt. (dwarf rabbitbrush)

Dwarf rabbitbrush is a small, irregularly branched, depressed shrub or subshrub 3 dm high or less, with numerous short branches arising from decumbent lower stems (fig. 40). The branches are covered with a dense scabrid pubescence. The narrowly oblanceolate to spatulate leaves are 0.7 to 2 cm long, 1 to 4 mm wide, and finely puberulent or scabrous like the branches.

The heads contain 5 disc flowers and are arranged into compact terminal cymes. Involucral bracts have mucronate to attenuate tips, are 10 to 13 mm long, and are arranged into 5 distinct vertical ranks. Achenes are 5 to 5.5 mm long and glabrous or obscurely pubescent toward their apex. The soft brownish-white pappus is slightly longer than the corolla. Blooming occurs from May to October.

Hybridization.--Chrysothamnus depressus has a chromosome number of $2n = 18$ (Anderson 1966). It is not known to hybridize with any other rabbitbrush.

Distribution and habitat.--This species occurs on dry plains, hills, and rocky mountain slopes from 1,000 to 2,100 meters in elevation (3,300 to 6,900 feet) scattered over western Colorado, New Mexico, Utah, Nevada, and southeastern California.

Figure 39.--Drawings of Chrysothamnus *taxa. (A)* C. albidus, *Robertson* s.n., *Wells, Elko Co., Nev. (1.1X). (B)* C. parryi *ssp.* attenuatus, *McArthur and Blauer SC 74-35, Wasatch Pass, Sevier Co., Utah (1.1X). (C)* C. parryi *ssp.* monocephalus, *McArthur and Blauer N-82, Slide Mountain, Washoe Co., Nev. (1.6X).*

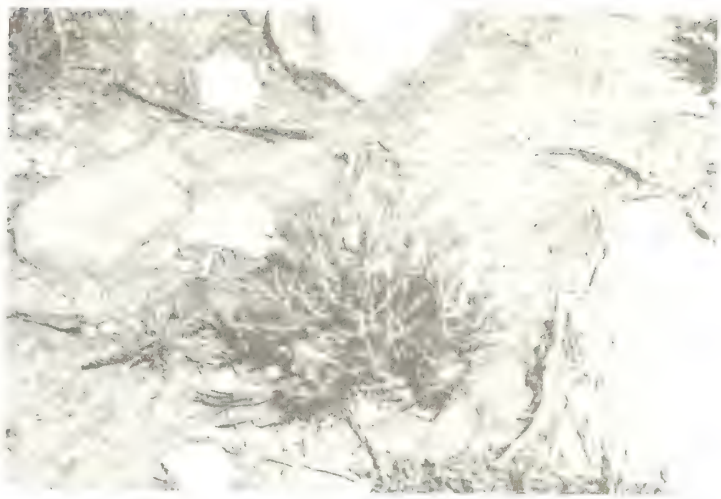


*Figure 40.--Dwarf rabbitbrush (*C. depressus*) growing near the mouth of Ephraim Canyon, Sanpete Co., Utah.*

Use.--Dwarf rabbitbrush is often heavily browsed by sheep, cattle, and wildlife (Hall and Clements 1923). It transplants readily and is useful for stabilizing depleted soils on which it readily grows. It is a source of protein when grasses and broadleaf herbs have dried.

Chrysothamnus greenei (Gray) Greene (Greenes rabbitbrush)

Greenes rabbitbrush is a small highly branched shrub only 1 to 3.5 dm high. Its glabrous brittle twigs are green at first but soon become white and shiny. Bark on the lower branches often peels off in sheets (Hall and Clements 1923). The nearly glabrous or slightly scabrous-ciliate leaves are narrowly linear, 1.2 m or less wide, 1 to 3.5 cm long, and are more or less viscidulous.

Flower heads normally contain 5 disc flowers in rounded or flat-topped cymes. The involucral bracts are 5 to 7 mm long, arranged in 5 poorly defined vertical ranks, and terminate in narrowly acuminate, greenish tips. The tubular to funnelform corollas may be whitish or yellow and 4 to 4.5 mm long. Achenes are about 3 mm long and are covered with dense, long, shaggy hairs.

Greenes rabbitbrush has been divided into 2 subspecies, ssp. *greenei* and ssp. *filifolius* by some authors (Hall and Clements 1923; Harrington 1954; and Kearney and Peebles 1960). These authors separate ssp. *filifolius* from *greenei* by its normally larger stature and shorter narrower leaves. We believe no subspecies should be recognized because the purported subspecies (1) are chromatographically similar (McArthur and others 1978) and (2) often occur in mixed populations. The chromatographic data from McArthur and others (1978) further suggest that *C. greenei* could be considered a subspecies of *C. viscidiflorus* rather than a separate species. *Chrysothamnus greenei* closely resembles *C. viscidiflorus*, particularly ssp. *stenophyllus*. Both have a low, bushy habit, white-barked stems, and short narrow leaves. Furthermore, the *axillaris* form of *stenophyllus* has involucral bracts with attenuate tips (Anderson 1964) that closely resemble those of *C. greenei*. We concur with Hall and Clements (1923) who felt the similarity between *C. greenei* and *C. viscidiflorus* indicated a close genetic relationship.

Hybridization.--*Chrysothamnus greenei* has a chromosome number of $2n = 18$ (Anderson 1966). Anderson (letter 3/30/76) believes *C. viscidiflorus* ssp. *stenophyllus* form *axillaris* "may represent some sort of introgression of *C. greenei* into *C. v. stenophyllus*."

Figure 41.--A large spreading rabbitbrush (C. linifolius) growing at the Snow Field Station.

Distribution and habitat.--Greenes rabbitbrush occurs on plains, valleys, and foothills in Colorado, New Mexico, Nevada, and Utah. Overgrazing allows it to greatly increase, sometimes forming a subclimax or even climax community (Halls and Clements 19

Use.--This species provides cover and browse in areas where it is abundant.

Chrysothamnus linifolius Greene (spreading rabbitbrush)

Spreading rabbitbrush is a tall, robust shrub up to 2.4 meters high (fig. 41). *Chrysothamnus linifolius* spreads underground by lateral roots that form adventitious shoots (fig. 42) (Anderson 1964). In the genus, only *C. parryi* shares the underground spreading trait and then not nearly to the extent *C. linifolius* does. Leaves are lar flat, green, glabrous, lanceolate to oblong-lanceolate, 2 to 5 cm long, and 4 to 8 mm wide.

Heads contain 4 to 6, usually 5 disc flowers and are arranged into broad, loose cymes. The involucral bracts have obtuse tips with thickened green spots similar to those of *C. vaseyi*. These spots, however, dry to a brown color. Achenes are covered

Figure 42.--Root sprouts, foreground, of spreading rabbitbrush (C. linifolius) at the Snow Field Station.

with dense, long, soft hair. Blooming occurs during August and September. Cleaned seed averages 3,140 per gram (1,425,000 per pound).

Hybridization.--*Type* [illegible]
(Anderson 1966 and 1971). Hall and Clements (1923) reported that intermediates showing all gradations in characteristics between *C. linifolius* and *C. viscidiflorus* ssp. *typicus* (*viscidiflorus*) have been noted in the area around Point of Rocks, Wyoming.

Distribution and habitat.--Spreading [illegible]
Mexico, Utah, and Nevada. It is most abundant in alkaline soils along roadcuts, barrow pits, ditches, streams, and washes in the Upper Colorado River drainage.

Use.--The aggressive underground spreading characteristics of the species make it a valuable stabilizer of disturbed alkaline soils (McArthur and others 1974; Plummer 1977).

Chrysothamnus nauseosus (Pallas) Britt. (rubber rabbitbrush)

Rubber rabbitbrush is a shrub usually 3 to 20 dm high, but it varies from dwarf forms to types over 3 m high. Usually, several erect stems arise from the base and these branch to form rounded bushes. Branches are covered with a green, yellow green, gray-green to white feltlike tomentum usually infiltrated with a resinous gum, making the plant somewhat sticky. This coating is often mistaken for part of the bark but can be discerned by scraping with a knife edge or a fingernail.

Leaves are nearly filiform in some subspecies to broadly linear in others. Leaves vary from 18 to 63 mm long and are covered with a tomentose vestiture. They are not twisted or gland-dotted.

The heads of this species are usually arranged into a cymose inflorescence. Each head bears 20 to 25 glabrous to densely tometose involucral bracts arranged in up to 5 vertical rows (fig. 36a). Rubber rabbitbrush blooms from August to October. Plants at higher elevations bloom earlier than those at lower elevations. Most forms of *C. nauseosus* are among the latest bloomers of the genus. Close examination of the buds and flowers in various stages of development revealed that the anthers open to release pollen during late bud and just as the buds are opening. As the bud continues to open, the anther tube is pushed above the corolla by elongating filaments. At the same time, the styles elongate and push the stigmas up through the anther tube until the stigmas are fully exserted at full bloom. The stigmas then separate to expose their receptive inner surface (fig. 38). By this stage of development, most, if not all, pollen from the anther tube of the same flower has been shed. The later maturing stigmas, particularly from the first flowers to bloom on an individual shrub, indicate that *Chrysothamnus* is predominantly self-fertilized (Anderson 1966) because pollen from later developing flowers in the same head, or from other heads on the same bush, may be transferred to receptive flowers on that bush. This genus is not apomictic (Anderson 1966). Fruits mature in October and November. Cleaned seed averages 1,530 per gram (693,000 per pound) (Plummer and others 1968).

We have recently discovered that galls induced by tephritid flies are differentially distributed among the subspecies of rubber rabbitbrush (McArthur and others 1979). Over much of its range, ssp. *albicaulis* is infested with a persistent round stem gall, 0.3 to 1.2 cm in diameter (fig. 43). In our observations, this gall was restricted to ssp. *albicaulis*. Subspecies *consimilis* and *nauseosus*, on the other hand, have a less persistent, fluffy stem gall reminiscent of a ball of cotton about 0.7 to 1.4 cm in diameter (fig. 43). This gall is found also on ssp. *albicaulis* in southern areas (near Kanab, Utah, and Colorado City, Arizona). The round gall is absent in these

Figure 43.--Contrasting tephritid galls on C. nauseosus *subspecies. (A.) Callus gall on ssp.* albicaulis. *(B.) Cotton gall on ssp.* graveolens. *Specimens from Gould's Wash, Washington Co., Utah.*

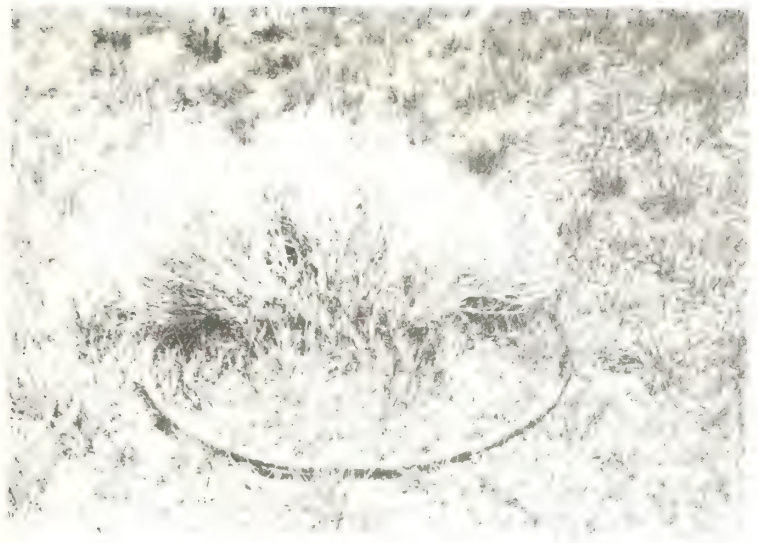
areas. We are currently studying the absolute specificity of these galls. In areas where these subspecies occur together the galls are very specific. We have observed only a few cases of cross gall inoculation and then only on putative hybrid plants. Wangberg (1976) independently observed some species and subspecies specificity of tephritid galls on *Chrysothamnus* in Idaho. Wangberg (1976) found less specificity for the round gall in Idaho than we did in Utah. He identified the tephritid flies that induce the galls as two different species of *Aciurina*.

Hybridization.--Chrysothamnus nauseosus has a chromosome number of $2n = 18$ (Anderson 1966, 1971; Kovanda 1972; Anderson and others 1974). This rabbitbrush is a highly variable species of numerous ecotypes and biotypes from which a large number of segregates have been described. Most important among these, in the Great Basin at least, are the subspecies: *salicifolius, albicaulis, graveolens,* and *consimilis*. Other less common and less important subspecies include: *junceus, gnaphalodes, hololeucus, leiospermus,* and *turbinaturs*.

L. C. Anderson (letter 4/12/72) advised using *C. nauseosus* in hybridization programs since all the natural *Chrysothamnus* hybrids he had found involved this species. Anderson has found hybrids of *C. nauseosus* ssp. *nauseosus* X *C. parryi* ssp. *parryi*, *C. albidus* X *C. nauseosus*, and *C. nauseosus* ssp. *albicaulis* X *Haplopappus macronema*. The last named combination is the putative parentage of the rare endemic *C. bolanderi* (Anderson and Reveal 1966). In 1966 there were only 25-50 plants of this species--all at Mono Pass, California. In his artificial hybridization attempts, Anderson (letter 4/12/72) inserted pollen between the appressed stigmatic lobes before they separated naturally. This technique produced no hybrids but did block self-pollination in several cases so that the recipient flowers set no seed.

During our field studies of intermixed *albicaulis-consimilis, albicaulis-graveolens,* and *graveolens-consimilis* populations, we consistently found considerable intermixing of color and leaf characteristics, indicating that introgression had occurred. Our work with paper chromatography supports this observation (Hanks and others 1975). We found plants intermediate between *C. nauseosus* ssp. *salicifolius* and *C. parryi* ssp. *nevadensis* and *howardi* in Utah and Nevada, respectively. The subspecies of *C. nauseosus* found in Colorado intergrade to some degree, according to Harrington (1954).

We agree with Hall and Clements (1923) that "improvement in any desired direction may be brought about by selection, or by hybridization, or by both of these methods."



rabbitbrush (C. nauseosus ssp. albicaulis in a thick stand of [illegible] intermedia cristatum)] at Tigaon [illegible], Utah.

Distribution and Habitat --Rubber rabbitbrush ranges from British Columbia and Saskatchewan south to western Texas, Baja California, and eastern California. It is a common plant on plains, valleys, and foothills. It grows best in openings within the sagebrush, juniper-pinyon, and ponderosa pine zones in sandy, gravelly, or clay-alkaline soils. This species grows at elevations ranging from 150 to 2,750 meters (500 to 9,000 feet).

Rubber rabbitbrush vigorously invades disturbed sites such as roadcuts and overgrazed rangelands. On ranges where big sagebrush has been destroyed by fire, insects, vehicular traffic, or continued heavy grazing, rabbitbrush increases and often becomes the dominant vegetation (Evans and others 1973). Nevertheless, in most habitats, this species is not overly competitive with herbaceous species and on some sites it does not suppress grass. Production of herbaceous cover and percentage of site covered have been notably greater when rabbitbrush is present than when it is not present (Plummer 1959; Plummer and others 1968) (fig. 44).

Use.--Rubber rabbitbrush is an excellent plant for controlling erosion because of its deep roots, heavy litter, and ability to establish on severe sites (USDA Forest Service 1974). Once established, this species reproduces easily and spreads fast from its light, plumed, wind-disseminated achene. It also grows vigorously when transplanted. When cut and divided the crown readily forms basal sprouts (Hall and Clements 1923).

The value of *C. nauseosus* as browse varies greatly between subspecies and ecotypes. The white to grayish subspecies such as *albicaulis* and *salicifolius* are more palatable to livestock and big game than the green subspecies, *graveolens* and *consimilis* (fig. 45. McArthur and others 1974; Hanks and others 1975). Throughout much of the summer range, game and livestock browse the plant lightly if at all except under unusual conditions. During late summer and fall when rubber rabbitbrush is in bloom, most livestock and game graze the flowers, and occasionally a few leaves and the more tender stems. Rubber rabbitbrush is most heavily browsed on winter ranges (fig. 46). Rubber rabbitbrush was found in 48 percent of the deer stomachs examined on a portion of winter range in Owens Valley, Inyo County, California, although it never amounted to more than 6 percent of the total food ingested (Sampson and Jesperson 1963). Crude protein content ranged from 9 percent during the dormant months to 11.8 percent in the spring after new leaves had formed (Sampson and Jesperson 1963).

Subspecies.--*Chrysothamnus nauseosus* ssp. *albicaulis* (white rubber rabbitbrush) is a shrub from 6 to 20 dm high with erect leafy branches and leaves covered with a

*Figure 45.--Differential deer browsing on subspecies of rubber rabbitbrush on Bald Mountain, Sanpete Co., Utah. The dark plant (lower left) is the threadleaf rubber rabbitbrush (*C. nauseosus *ssp.* consimilis*), whereas the light plant (center) is white rubber rabbitbrush (*C. nauseosus *ssp.* albicaulis*).*

permanent, dense, white to grayish tomentum (fig. 47). The leaves are 2.5 to 4 cm lo 0.5 to 1.5 mm wide or sometimes to 3 mm wide in a few forms (fig. 48a). The strongly keeled, acute involucral bracts (fig. 38a) are white, more or less tomentose, 8 to 10 mm long, and arranged into 5 distinct vertical ranks. The yellow corollas are 8 to 1 mm long and terminate in lobes 1 to 2 mm long. The achenes are densely pubescent. White rubber rabbitbrush is a common and widespread subspecies found in open places i plains and foothills from British Columbia and Montana southward to northwestern Colorado, Utah, Nevada, and eastern California. It is most abundant in the Great Bas area (Hall and Clements 1923). This subspecies is often found intermixed with ssp. *graveolens* on foothill ranges, and with ssp. *consimilis* in valleys and plains (Plumme 1977). The striking white forms have potential use as ornamentals.

Chrysothamnus nauseosus ssp. *consimilis* (threadleaf rubber rabbitbrush) may reac 3 m in height when mature (fig. 49). It has leafy, erect branches covered with a gre to yellow-green dense tomentum. The very narrow threadlike (linear-filiform) leaves are less than 1 mm wide and 2.5 to 5 cm long (figs. 48b, 50). They are usually cover with a green to yellow-green tomentum and are somewhat resinous. When crushed, the leaves and twigs emit a strongly disagreeable odor. The involucral bracts are acute,

*Figure 46.--Sheep browsi white rubber rabbitbru (*C. nauseosus *ssp.* albicaulis*) near Ephra Sanpete Co., Utah.*

*Figure 47.--A white rubber rabbitbrush (*C. nauseosus *ssp.* albicaulis*) growing near Fountain Green, Sanpete Co., Utah. The stake is 1.5 m tall.*

glabrous, and keeled and are arranged in fairly distinct vertical rows. The bracts are 6.5 to 8.5 mm long. The corollas are 7 to 9.5 mm long, with glabrous lobes 1 to 2.5 mm long. The achenes are densely pubescent, suggesting that this subspecies may be a connecting link between rubber rabbitbrush and low rabbitbrush.

Chromatograms of threadleaf rubber rabbitbrush were found to [illegible] to those of the *C. viscidiflorus* complex (Hanks and others 1975). Subspecies *consimilis* is most common in alkaline valleys and plains of the Great Basin where it is often associated with various saltbushes. In less alkaline areas *consimilis* mixes with ssp. *albicaulis* and *graveolens*. *Consimilis* also occurs on [illegible] soil outside the Great Basin from western Wyoming, Colorado, and New Mexico to northern Oregon and eastern California. A large ecotype that occurs principally in the [illegible] part of its range was formerly recognized as a separate subspecies, *viridulus*. Another subspecies, *pinifolius*, has also been reduced to synonymy with [illegible]. Plants formerly referred to as *pinifolius* grow in southern Colorado and New Mexico. Threadleaf rubber rabbitbrush is one of the least palatable of the [illegible] species. It may therefore have value in revegetating disturbed sites such as roadcuts where attraction of browsing animals is not desired. This subspecies helps control [illegible] on open alkaline soils by providing ground cover and soil stabilization.

Chrysothamnus nauseosus ssp. *graveolens* (green rubber rabbitbrush) ranges from 6 to 15 dm high when mature (fig. 51). Its leafy, erect branches are yellow-green to green or sometimes gray-green and are covered with a compact tomentum. The linear leaves are 1 to 3 mm wide, 4 to 6 cm long, and only slightly pubescent (fig. 48c). The involucral bracts are 6 to 8 mm long, glabrous at least on their backs, acute, keeled, and arranged in vertical rows. The yellow corollas are 7 to 9 mm long with lobes 0.5 to 1.5 mm long. Achenes are densely pubescent. Green rubber rabbitbrush is widespread and sporadic from North Dakota to Idaho and southward to western Texas, New Mexico, and Arizona. It is most common on well-drained foothills (fig. 52), but also extends up into the mountains and down into valleys and plains where it is often found intermixed with ssp. *consimilis*. Green rubber rabbitbrush is generally less palatable than the white or grey subspecies, *albicaulis* and *salicifolius*. Nevertheless, some forms of this subspecies have been found which are utilized to a moderate degree by livestock and mule deer.

Chrysothamnus nauseosus ssp. *salicifolius* (mountain rubber rabbitbrush) is a shrub from 3 to 20 dm high (fig. 53). Its ascending to erect twigs are very leafy and are

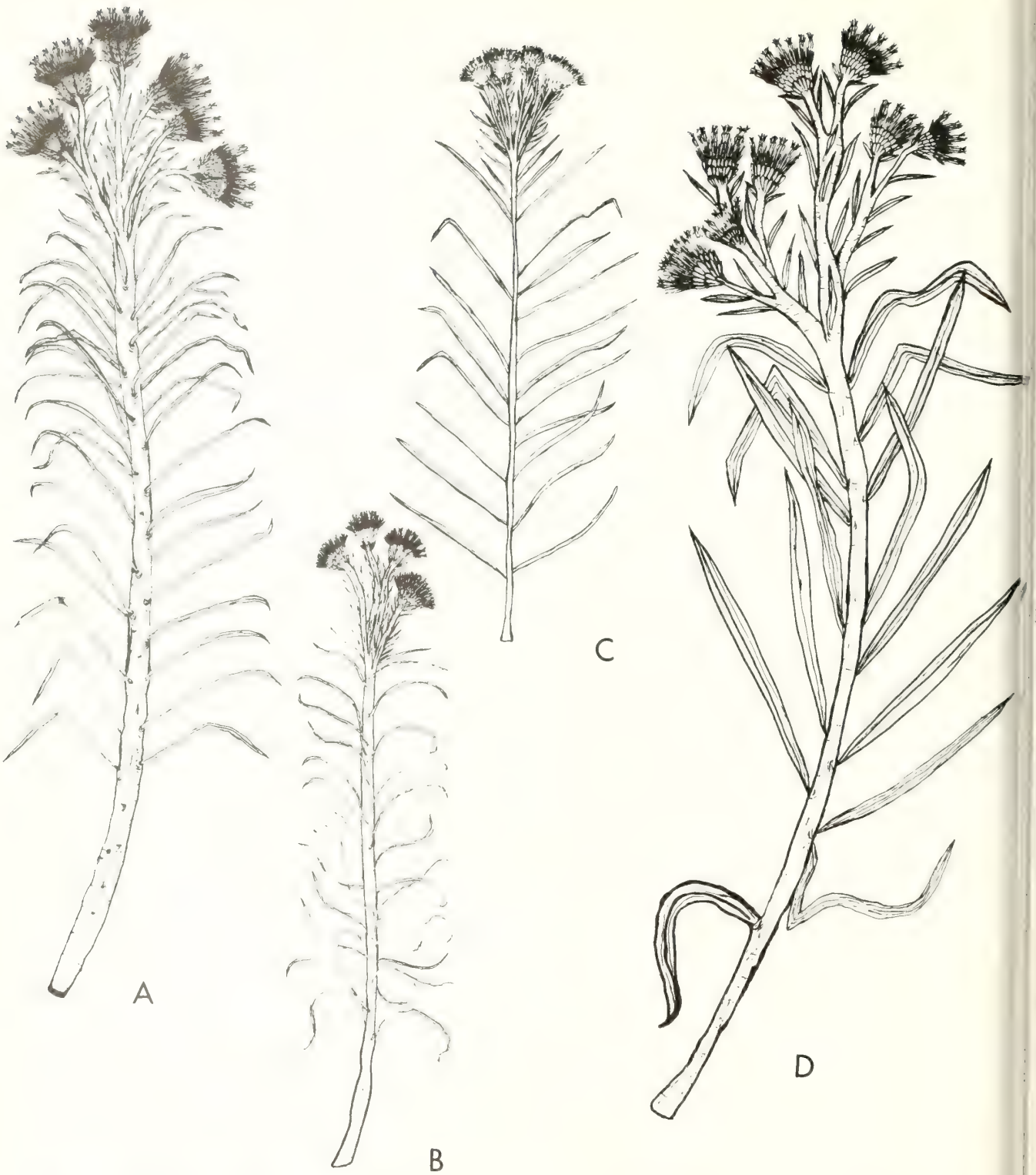


Figure 48.--Drawing of subspecies of Chrysothamnus nauseosus *(A.)* C. nauseosus *ssp.* albicaulis, *McArthur and Blauer N-18, Wells, Elko Co., Nev. (0.8X). (B.)* C. nauseosus *ssp.* consimilis, *McArthur and Blauer N-42, Deeth, Elko Co., Nev. (0.6X). (C.)* C. nauseosus *ssp.* graveolens, *Blauer 291A, Henryville, Garfield Co., Utah (0.5X). (D.)* C. nauseosus *ssp.* salicifolius, *Tierman* s.n., *Strawberry Valley, Wasatch Co., Utah (1.1X).*

igure 49.--A threadleaf rubber rabbitbrush (C. nauseosus ssp. consimilis) growing near Ephraim, Sanpete Co., Utah.

igure 50.--Stem, leaves, and inflorescences of threadleaf rubber rabbitbrush on plant near Ephraim, Sanpete Co., Utah.

igure 51.--Green rubber rabbitbrush (C. nauseosus ssp. graveolens) growing at the Snow Field Station.

*Figure 52.--Green rubber rabbitbrush (*C. nauseosus *ssp.* graveolens*) growing at Wasatch Pass, Sevier Co., Utah.*

covered with a gray-green, fairly compact tomentum. The leaves are broadly linear, ranging from 4 to 8 cm long and 3 to 10 mm wide, which makes them the largest leaves of the species (fig. 48d). The involucral bracts are 7 to 8 mm long, mostly obtuse, nearly glabrous, and arranged in rather obscure ranks (fig. 36b). The yellow corollas are about 1 cm long and have a minutely pubescent throat. The achenes are densely pubescent. Mountain rubber rabbitbrush was reported by Hall and Clements (1923) to be "apparently rare and confined to Utah." However, we have found it to be fairly widespread at higher elevations in Utah and parts of Nevada (East Humboldt Range, Elko County; and Mt. Charleston, Clark County) as part of the lower subalpine vegetation (fig. 54). L. C. Anderson (letter 3/30/76) considered our Nevada specimens to be ssp. *albicaulis*. So far as we can determine, these specimens do not differ in any important respects from ssp. *salicifolius* growing at its type location (Strawberry Valley, Wasatch County, Utah). It extends down to the foothills in parts of its range where it may be found intermixed with ssp. *albicaulis* and *graveolens* (Plummer 1977). Mountain rubber rabbitbrush appears to be the most palatable subspecies of the four common subspecies, *salicifolius, albicaulis, graveolens,* and *consimilis* in Utah (Plummer 1977).

Other less common subspecies which, however, have locally large populations include *junceus, hololeucus,* and *leiospermus*. Subspecies *junceus* is a nearly leafless,

*Figure 53.--Mountain rubber rabbitbrush (*C. nauseosus *ssp.* salicifolius*) growing at the Snow Field Station.*

*Figure 54.--Mountain rubber rabbitbrush (*C. nauseosus *ssp.* salicifolius*) growing on Strawberry Ridge on the Utah-Wasatch Co. line, Utah.*

yellow-green form adapted to sandy areas in the Colorado River drainage. Subspecies *hololeucus* is a Great Basin foothill and valley form similar to ssp. *albicaulis*. It differs from the latter subspecies only in cryptic floral and achene characteristics. Subspecies *leiospermus* is a low shrub usually less than a meter in height. It has affinities to ssp. *consimilis*. It occurs mostly on arid sites in the southern part of the Great Basin. A distinguishing feature of ssp. *leiospermus* is its glabrous or nearly glabrous achenes.

A few additional subspecies occur principally outside of the Intermountain area. These include *nauseosus* (mostly on the western edge of the northern Great Basin), *mohavensis* (southern California), and *turbinatus* (Colorado plateau).

Chrysothamnus parryi (Gray) Greene (parry rabbitbrush)

Parry rabbitbrush is a shrubby species somewhat intermediate in height, stem and leaf tomentum, and growth habit between rubber rabbitbrush and low rabbitbrush. Parry rabbitbrush is a low, dense shrub similar in habit to certain forms of *C. viscidiflorus*. It is usually from 2 to 6 dm in height with numerous spreading to erect flexible branches (fig. 55). Like *C. nauseosus*, the branches of Parry rabbitbrush are covered

*Figure 55.--Howard rabbitbrush (*C. parryi *ssp.* howardi*) growing at Current Creek, Duchesne Co., Utah.*

with a feltlike white to green tomentum. The tomentum, however, is neither as dense no resinous as in rubber rabbitbrush. Paulsen and Miller (1968) observed that Parry rabbitbrush spread from underground roots. We have recently confirmed this phenomenon in ssp. *attenuatus*.

The glabrous to tomentulose, somewhat viscid leaves are narrowly linear to elliptic, and range in size from 0.5 to 8 mm wide and 1 to 8 cm long.

Flower heads usually are arranged in terminal leafy racemes (fig. 35) that sometimes form panicles. The involucral bracts are 9 to 14 mm high and terminate in acuminate to very attenuate herbaceous tips (fig. 36c). The yellow, tubular to funnelform corollas are 8 to 11 mm long. Achenes are 5 to 6 mm long and are covered with long, shaggy, appressed hairs. Blooming occurs from July to September. Cleaned seeds average 550 per gram (250,000 per pound).

Hybridization.--Chrysothamnus parryi has $2n = 18$ chromosomes (Anderson 1966, 1969, 1971). This species is composed of 10 subspecies, 6 of which occur in the Intermountain region (Hall and Clements 1923). Among the *Chrysothamnii*, *Chrysothamnus parryi* is probably most closely related to *C. nauseosus* with which it shares similarities in pubescence, corolla, shape, and style-branches. In our fieldwork through Utah and Nevada, we have found plants intermediate between *C. nauseosus* ssp. *salicifolius* and *C. parryi*. Within the species, intermediate forms are known to occur between ssp. *parryi* and *howardi* and between *howardi* and *attenuatus* (Hall and Clements 1923).

Distribution and habitat.--Parry rabbitbrush occurs in dry, open places in mountains and foothills of western North America from Wyoming and western Nebraska west to California and south to New Mexico and Arizona. Like other species of rabbitbrush, this species tends to increase on overgrazed and disturbed areas.

Use.--Although this species is generally palatable, it is not as widespread or abundant as rubber rabbitbrush and low rabbitbrush and thus not as important for forage. It is browsed mainly during periods of drought, particularly the more abundant subspecies of *attenuatus*, *howardi*, and *parryi*. Parry rabbitbrush has potential value for stabilizing disturbed soils. We have observed several of its subspecies on roadcuts and fills.

Subspecies.--Chrysothamnus parryi ssp. *asper* is a low shrub 1.5 dm or more high with slightly spreading to erect branches. Its green leaves, roughened with short-stalked resin glands, are 2 to 5 cm long and 1 to 3 mm wide. The heads contain 5 to 10 disc flowers and are subtended by somewhat ranked involucral bracts with straight tips. This subspecies occurs on mountainsides bordering desert areas from 2,100 to 2,600 meters (6,900 to 8,500 feet) in elevation in western Nevada and eastern California. Its type locality is listed as "Hockett trail, in the valley of Little Cottonwood Creek, eastern slope of the Sierra Nevada of Inyo Co., Cal." (Hall and Clements 1923).

Chrysothamnus parryi ssp. *attenuatus* consists of low shrubs with mostly erect stems up to 6 dm high. It has green, slightly viscid, narrowly linear leaves, 2 to 4 mm long and about 1 mm wide (fig. 39b). The leaves are erect but are not larger than the inflorescence. Heads contain 5 to 7 disc flowers and are subtended by involucral bracts with slender, straight tips. The bracts are ranked into 5 vertical rows. Blooming occurs from August to October. Subspecies *attenuatus* is found in the sagebrush, pinyon-juniper, and yellow pine vegetational types from southern Idaho to Nebraska and south to New Mexico, Arizona, and California. Its type locality is listed as "Marysvale, Utah, at 2,150 m in clay" (Hall and Clements 1923). We recently noted that this subspecies will spread by adventitious shoots from underground roots.

Chrysothamnus parryi ssp. *howardi* (Howard rabbitbrush) is a low shrub (fig. 35). Its spreading basal stems and erect branches are up to 6 dm high (fig. 55). The narrowly linear, tomentose leaves are 2 to 4 cm long, about 1 mm wide, and the upper ones

usually extend beyond the uppermost head of the [illegible]. [illegible] 5 to 7 pale yellow disc flowers. The heads are subtended by vertically ranked involucral bracts usually with spreading tips. Blooming occurs from July to September. This subspecies occurs on dry hills and mesas associated with sagebrush, pinyon-juniper, and yellow pine vegetational types in Utah, western Wyoming, Colorado, New Mexico, and Nebraska. Type locality is listed as "gravelly hills near 'Hot Springs' of Middle Park, Colo." (Hall and Clements 1923).

Chrysothamnus parryi ssp. *[illegible]* is a low shrub [illegible] rigid, spreading branches. Its viscid, somewhat tomentulose leaves are linear-oblanceolate or spatulate, 1 to 3 cm long, and 1.5 cm or less wide (fig. 39e). The upper leaves usually extend beyond the inflorescence. The flowering heads occur singly or in pairs on the end of short leafy branches. The heads contain 5 or 6 disc flowers and are subtended by obscurely ranked involucral bracts with straight, attenuate tips. This subspecies occurs in the high mountains of western Nevada and eastern California on dry rocky slopes between 3,000 to 3,400 meters (9,800 to 11,200 feet). Its type locality is listed as "summit of Mount Rose, Washoe, Co., Nev." (Hall and Clements 1923).

Chrysothamnus parryi ssp. *nevadensis* (Nevada rabbitbrush) consists of low shrubs with ascending to erect branches up to 6 dm high. The linear to linear-oblanceolate leaves are 1.5 to 4 cm long, 0.5 to 3 mm wide, and sometimes green to resinous, but usually gray-tomentose. The uppermost leaves rarely extend beyond the inflorescence. The flowering heads contain 4 to 6 yellow disc flowers and are subtended by ranked involucral bracts with slender recurved tips. *Chrysothamnus parryi* ssp. *nevadensis* occurs between 1,300 and 2,700 meters (4,300 and 8,900 feet) in elevation on dry mountain sides from eastern California to eastern Nevada, southwestern Utah, and northern Arizona. It is most common along the eastern flank of the Sierra Nevada. Type locality is Mount Davidson, Nevada (Hall and Clements 1923).

Chrysothamnus parryi ssp. *parryi* (Parry rabbitbrush) consists of low shrubs with erect branches 3 dm or more high. The uppermost leaves usually extend beyond the inflorescence. Flowering heads contain 10 to 20 disc flowers and are subtended by obscurely ranked involucral bracts with straight attenuate tips. Blooms occur during August and September. Subspecies *parryi* grows in dry plains, valleys, and hillsides in northeastern Nevada, Utah, Wyoming, and Colorado. Type locality is listed as "Rocky Mountains, latitude 39° to 41°" (Hall and Clements 1923).

There are a few other subspecies of *C. parryi* such as *imulus* and *[illegible]*. These occur outside of or only on the fringe of the Intermountain area and in small numbers (Hall and Clements 1923).

Chrysothamnus vaseyi (Gray) Greene (Vasey rabbitbrush)

Vasey rabbitbrush is a low, rounded shrub with ascending to erect branches up to 3 dm high. The bark on the young branches is pale green to whitish and glabrous, becoming brown and fibrous with age. Leaves are linear to linear-oblanceolate, 1 to 2.5 cm long, 1 to 3 mm wide, and glabrous.

Heads contain 5 to 7 disc flowers each and are arranged into small, compact cymes. The obscurely ranked involucral bracts are 5 to 7 mm high, oblong, obtuse to rounded, and all but the innermost have a thickened greenish spot near the apex. The achenes are about 5 mm long, terete, longitudinally 10-striate, and glabrous. Blooming occurs from July to September.

Hybridization.--This species [illegible]. The populations of *C. vaseyi* seem fairly stable with little variation (Hall and Clements 1923).

Distribution and Habitat.--*Chrysothamnus vaseyi* occurs scattered over plains, hillsides, and mountain valleys at altitudes of 1,700 to 2,600 meters (5,600 to 8,500 feet) in Utah, Wyoming, Colorado, New Mexico, and Arizona (Hall and Clements 1923).

Use.--This shrub is probably browsed by sheep, but is small and so scattered it is of little value.

Chrysothamnus Viscidiflorus (Hook.) Nutt. (low rabbitbrush[7])

Low rabbitbrush varies in appearance and foliage characteristics. It is usually 3 dm to 1 m tall with many erect stems branching from a simple base. The brittle, erect twigs are glabrous or puberulent with pale green or white bark.

Leaves are narrowly linear to oblong or lanceolate, 1 to 6 cm long and often twisted. Leaf vestiture is glabrous or pubescent and commonly viscidulous with usually scabrous margins. Degree of pubescence may vary tremendously in variants of this species. As Hall and Clements (1923) pointed out, sometimes the pubescence among the subspecies of *viscidiflorus* "will occur as a fairly dense though minute puberulence in certain plants, while others almost exactly duplicating these in every other respect will be perfectly glabrous." Furthermore, L. C. Anderson (letter 3/30/76) has observed good correlation between plant stature and leaf size of ssp. *viscidiflorus* and *lanceolatus* with altitude and amount of precipitation.

Flower heads containing approximately 5 perfect, fertile disc flowers each are arranged in compact terminal cymes. Involucral bracts number about 15 per head and are arranged in poorly to well defined vertical ranks. The bracts of some subspecies have a greenish or brownish thickened spot near their apex. Low rabbitbrush averages about 1,725 cleaned seeds per gram (782,000 per pound) (Plummer and others 1968).

Hybridization.--*Chrysothamnus viscidiflorus* is the center of a polyploid species complex with a basic chromosome number of $x = 9$. Diploid ($2n = 18$), triploid ($2n = 27$), tetraploid ($2n = 36$), pentaploid ($2n = 45$), and hexaploid ($2n = 54$) populations of this species are known to occur (Anderson 1966, 1971; Anderson and others 1974).

This species includes numerous subspecies and ecotypes within subspecies. Most important among these in the Great Basin are 2 glabrous subspecies, *viscidiflorus* and *stenophyllus*, and 2 pubescent subspecies, *lanceolatus* and *puberulus* (fig. 56). Hall and Clements (1923) believe numerous intergrades have been held together in one rather close species through interbreeding where their ranges meet or overlap. Abrams and Ferris (1960) describe *C. viscidiflorus* as a highly polymorphic species composed of several freely intergrading subspecies of overlapping distribution. We invariably find intermediates when doing fieldwork on this species. We believe forms of low rabbitbrush may be improved for grazing and other uses through selection and breeding. Because each subspecies is self-fertile and predominately self-pollinated, each maintains its identity despite occasional outcrossing (McArthur and others 1978).

Distribution and habitat.--Low rabbitbrush is one of the most widely distributed shrubs on rangelands throughout western North America. It occurs in dry, open areas from British Columbia and North Dakota, south to New Mexico, Arizona, and eastern California at elevations between 790 and 3,350 meters (2,600 and 11,000 feet). Low rabbitbrush is usually associated with sagebrush, snakeweed (*Xanthocephalum*), and other species of rabbitbrush.

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[7]Other common names include yellowbrush, yellow rabbitbrush, yellowsage, rabbitsage, sticky-leaved rabbitbrush, and Douglas rabbitbrush.

Figure 56.-- [illegible] of Chrysothamnus viscidiflorus. [illegible] viscidiflorus ssp. lanceolatus, *McArthur and Blauer EC74-32, Wasatch Plateau, Sanpete Co., Utah (1.9X).* (B.) C. viscidiflorus ssp. puberulus, [illegible] *Canyon, Sanpete Co., Utah (0.9X).* (C.) C. viscidiflorus ssp. stenophyllus, *McArthur and Blauer EC74-18,* [illegible] viscidiflorus, *McArthur and Blauer SC74-7, Salina Canyon, Sevier Co., Utah (1.1X).*

Use.--This shrub may provide an important supply of browse to both game and livestock, particularly during late fall and winter after more desirable forage has been utilized. Throughout the Great Basin, low rabbitbrush, especially the flowering shoots provides good sheep feed. In California small amounts of low rabbitbrush were found in 10 to 14.8 percent of a large number of deer stomachs examined between October and January (Sampson and Jespersen 1963). There is much variation in palatability among the different subspecies. Some may be heavily utilized, whereas others are utilized little if at all (McArthur and others 1974). Subspecies *stenophyllus* on rocky foothills is often heavily used and sometimes destructively so, with animals preferring mature or partially mature plants to green immature ones. On a Utah winter range, this subspecies averaged up to 11.31 percent by weight of the diet of sheep (Cook and Harris 1950; Cook and others 1954). We have observed substantial use on ssp. *lanceolatus* in widely scattered areas of Utah and Nevada.

Antelope, elk, and bighorn sheep, as well as deer and livestock, show varying preferences for low rabbitbrush, depending on season, locality, and subspecies.

This species, like rubber rabbitbrush, increases rapidly and vigorously on overgrazed or otherwise disturbed sites. Some subspecies such as stickyleaf low rabbitbrush (ssp. *viscidiflorus*) and mountain low rabbitbrush (ssp. *lanceolatus*) adapt well to higher elevations while other subspecies such as narrow-leaf low rabbitbrush (ssp. *stenophyllus*) and hairy low rabbitbrush (ssp. *puberulus*) do best in lower desert and foothill habitats (Plummer 1977). Low rabbitbrush is valuable for revegetating depleted rangelands and other disturbed sites, such as strip mines and roadsides.

Subspecies.--*Chrysothamnus viscidiflorus* ssp. *lanceolatus* (mountain low rabbitbrush) is a small shrub from 2 to 5 dm tall (figs. 56a, 57). Its branches are straw-colored or gray and are finely pubescent. Flower heads are borne in small compact cymes with densely pubescent branches. Involucral bracts are 5 to 6.5 mm long, lanceolate to oblong, obtuse, and glabrous to pubescent. Achenes are densely strigose. On the basis of his systematic investigations in the genus *Chrysothamnus*, L. C. Anderson (letter dated 5/17/76) recommended placing the former ssp. *elegans* in synonomy with *C. viscidiflorus* ssp. *lanceolatus*. Our chromatographic work (McArthur and others 1978) supports this consolidation. Specimens we collected as *elegans* could easily be placed in ssp. *lanceolatus* or *puberulus*, depending on leaf width characteristics. Mountain low rabbitbrush is widespread and fairly common in dry foothill and mountainous habitats from 1,520 to 3,200 meters (5,000 to 10,500 feet) ranging from British Columbia, east to Montana, and south to New Mexico, Utah, and Nevada. This subspecies may be found

*Figure 57.--Mountain low rabbitbrush (*C. viscidiflorus *ssp.* lanceolatus*) growing at the Snow Field Station.*

growing with such shrubs as big sagebrush, snakeweed, various subspecies of rubber rabbitbrush (ssp. *salicifolius*, *albicaulis*, and *graveolens*), other subspecies of low rabbitbrush (*stenophyllus*, *viscidiflorus*, and *greenei*), and Parry rabbitbrush (*C. parryi*).

Chrysothamnus viscidiflorus ssp. [illegible] shrub up to 5 dm high with yellowish to green, finely pubescent branches (fig. 58). Its linear-filiform to linear leaves are sparsely to densely pubescent with scabrid-ciliate margins, and are usually twisted or revolute. The leaves are up to 2 mm wide and up to 3 cm long (fig. 56b). Flower heads are borne in small compact cymes with densely pubescent branches. Involucral bracts are about 5 to 6 mm long, lanceolate to oblong, acute to obtuse, and are usually marked with a thickened greenish spot near their tips. Hairy low rabbitbrush occurs on dry plains, valleys, and foothills, especially on poorer soils and disturbed areas. Its range extends from British Columbia to Montana northward to New Mexico, Arizona, Nevada, and eastern California. This subspecies is most abundant in the big sagebrush communities of western Utah, Nevada, and southern Idaho. However, it has been found growing in one locality or another with most of the other subspecies of low rabbitbrush, shadscale, winterfat, halogeton (*Halogeton glomeratus*), and occasionally with pinyon and juniper.

Chrysothamnus viscidiflorus ssp. *stenophyllus* (narrowleaf low rabbitbrush) [illegible] low, glabrous shrub up to 3 dm high with white bark. Leaves are linear-filiform, [illegible] twisted, viscidulous, 1 mm or less wide, 1 to 3 cm long, and glabrous except for [illegible] usually scabrid and revolute margins (fig. 56c). The branches of the small, compact cymes are glabrous. Involucral bracts are 4 to 6 cm long, not keeled, and [illegible]-oblong. Narrowleaf low rabbitbrush is rather common on most desert ranges, particularly in the southern portion of the Great Basin where it sometimes composes more than a [illegible] of the vegetative cover (Cook and others 1954). On these ranges this subspecies is usually found in the sagebrush type on poorer soils and disturbed sites, but is also found [illegible] ing with halophytes such as shadscale, fourwing saltbush (*Atriplex canescens*), [illegible] rease-wood, and halogeton. The species has special usefulness for providing cover on disturbed ranges in arid climates.

Chrysothamnus viscidiflorus ssp. *viscidiflorus* (stickyleaf low rabbitbrush) is the largest subspecies of low rabbitbrush. Mature shrubs are usually more than 5 dm tall, whereas the other subspecies are normally all under 5 dm. Its branches, leaves, and

*Figure 58.--Broom snakeweed (*X. sarothrae*) (right) growing next to hairy low rabbitbrush (*C. viscidiflorus *ssp.* puberulus*) near Ephraim, Sanpete Co., Utah.*

inflorescences are glabrous but viscid (sticky). The broadly linear to narrowly lanceolate, bright green leaves are 1 to 5 mm wide, 2 to 5 cm long, and flat or twisted (fig. 56d). Leaf margins are sometimes scabrid. Crushed foliage usually emits a very pungent odor. Branches of the cymes are glabrous. Involucral bracts are obtuse, oblong, not keeled, and 5 to 7 mm long. Stickyleaf low rabbitbrush is widely distributed on dry plains and hills from Washington, Idaho, and Montana south to Colorado, Utah, Nevada, and eastern California. It occurs primarily in sagebrush and pinyon-juniper communities at elevations between 1,520 and 2,600 meters (5,000 and 8,500 feet). This subspecies often becomes dominant in cleared or overgrazed areas. At lower elevations stickyleaf low rabbitbrush may be found associated with such halophytes as shadscale, winterfat, and halogeton. Other subspecies of low rabbitbrush are also often associated with it. Anderson (1971) recommends placing the former ssp. *pumilus* in synonymy with *C. viscidiflorus* ssp. *viscidiflorus* because its specimens are "only environmentally modified variants of *C. v.* ssp. *viscidiflorus*." Our chromatographic work (McArthur and others 1978) supports Anderson's reduction of *pumilus* to synonomy.

Because of its wide distribution from moist to arid sites, the species is well suited to a wide range of disturbed sites over the western States.

CHARACTERISTICS OF THE GENUS *TETRADYMIA* (HORSEBRUSH)

The genus *Tetradymia* consists of rather low, stiffly branched shrubs. The stems are uniformly canescent or have glabrous to woolly streaks running down the stem internodes from the primary leaves. The tomentum may be permanent or deciduous on both the stem and leaves. Spines may be present.

Tetradymia bears primary and secondary leaves. Primary leaves develop alternately along elongated shoots and are usually long-lived. These leaves are linear to spatulate and may form slender, straight, or recurved spines. Secondary leaves develop in fascicles in the axils of the primary leaves (fig. 59). They are generally short-lived and often dry up and fall away within a few weeks (Strother 1974).

Horsebrush flowers are borne in heads located singly or in pairs in the upper primary leaf or spine axils or are clustered in short, dense racemes or corymbs at the

Figure 59.--Primary (A) and secondary (B) leaves on Nuttall horsebrush (T. nuttallii). Specimen growing in Antelope Valley, Sanpete Co., Utah.

ips of branches. Each head contains from 4 to 9 yellow disc flowers. Ray flowers are acking. Four to 6 equal involucral bracts with overlapping sides subtend each head. he pappus consists of numerous bristles or scales or may be lacking. The ovary of ach flower develops into a glabrous to densely long-haired achene.

This genus blooms from April to August depending on elevation, climatic conditions, nd species. Numerous small moths, bees, flies, and beetles visit the flowers. Although numerous potential pollinators are available and the flowers are highly fertile, eedlings are not commonly seen in nature. This is probably due to the harsh environent in which *Tetradymia* is usually found (Strother 1974). However, we recently observed many young plants growing in a burned-over area near Wallsburg, Wasatch Co., tah.

The basic chromosome number for horsebrush is $x = 30$, and sporadically in some pecies, $x = 31$. Polyploidy occurs in the genus but has only been found in some spineess species (*T. filifolia, T. canescens, T. glabrata*). Strother (1974) found no orrelation between either geography or elevation of populations and their chromosome umber. He only rarely found variation of chromosome numbers within colonies.

Horsebrush provides some critically needed ground cover in the dry, sparsely egetated desert ranges where it grows. Although several species are poisonous to heep and have caused losses of thousands of animals in Utah and Nevada, horsebrush s browsed particularly heavily during winter and early spring on desert ranges and vergrazed areas where little else may be available this time of year. Most severe osses have occurred when hungry animals have been trailed from winter to summer anges through stands of horsebrush without allowing the animals a chance to graze ther plants (Kingsbury 1964). Considerable variation in toxicity within and between pecies of *Tetradymia* has been noted (Johnson 1974a, 1974b). Hopefully, through careul selection and study, palatable atoxic forms may be discovered and developed.

Four horsebrush species (*T. canescens*, *T. glabrata*, *T. nuttallii*, and *T. spinosa*) re quite common in the Intermountain area. *T. axillaris*, a spiny species, occurs on he edge of the Intermountain area in scattered populations from southwestern Utah to outhern California. Two other species are found southwest of the Intermountain area: . *argyraea* (southeastern California), and *T. comosa* (southern California and Baja California) (Strother 1974).

Tetradymia canescens DC. (Gray horsebrush[8])

Gray horsebrush is a spineless, much branched shrub up to 8 dm high (fig. 60). he branches are covered with a thick tomentum interrupted by glabrous to woolly treaks running down the stem internodes from the base of the primary leaves.

The primary leaves are linear-lanceolate to spatulate, 1 to 3 cm long, 2 to 4 mm ide, and are covered with a gray canescent to tomentose vestiture. The secondary eaves are shorter and narrower than the primary leaves, but are otherwise similar to hem.

Flower heads are borne on the tips of numerous short branches in corymb-like lusters. Each head contains 4 light yellow to cream disc flowers. Four lanceolate r ovate to oblong, canescent, involucral bracts subtend each head. The achenes are to 4 mm long and may be glabrous or hairy. The hairs when present are shorter than he abundant, well-developed pappus of bristles.

[8]Other common names include spineless horsebrush and black sage.

Figure 60.--Gray horsebrush (T. canescens) *growing at Wahsatch Station, Summit Co., Utah.*

This species begins flowering about mid-June in the northern part of its range (southern British Columbia and northeastern Washington) and progresses southward to San Bernardino County, California, and northern Arizona where it blooms in late July or early August (Strother 1974). Cleaned seed average 305 per gram (140,000 per pound).

Hybridization.--Gray horsebrush is a polyploid species with some aneuploidy at the diploid level. Sporadically, specimens with $2n = 62$ chromosomes are found in diploid populations ($2n = 60$). Triploid ($2n = 90$) and tetraploid ($2n = 120$) numbers are also known. Both diploid and triploid colonies are located throughout much of the range of *T. canescens* (Strother 1974).

Suggested hybrids between *T. canescens* and *T. glabrata* have been found in southern Idaho where the flowering period of these two species overlap (Strother 1974). A form with shorter and broader leaves, called *T. inermis*, occurs in Colorado, and plants intermediate between this form and the normal *T. canescens* are as common as the extremes (Harrington 1954).

Distribution and habitat.--The type locality for gray horsebrush is reported to be the Columbia River (Abram and Ferris 1960). It is widespread, however, throughout the Great Basin and adjacent areas, on dry plains, hills, and ridges from southern British Columbia, Montana, Idaho, and Washington southward to New Mexico, Arizona, and California between elevations of 400 and 3,300 meters (1,300 and 10,800 feet). Throughout its range it is associated with the sagebrush, pinyon-juniper, and yellow pine vegetation types (Strother 1974).

Use.--This species is generally regarded to be low in palatability to most animals and may be poisonous if large quantities are consumed. Nevertheless, buds and young leaves are frequently browsed during spring and fall months by sheep, goats, antelope, and deer. Cattle graze *T. canescens* fairly heavily in some areas in Nevada. This shrub probably has merit for establishing cover on severely depleted soils, such as mine spoils.

Tetradymia glabrata Torr. & Gray (littleleaf horsebrush)

Little-leaf horsebrush is a compact, heavily branched shrub up to 12 dm high. The vestiture of its young stems resembles that of gray horsebrush by having glabrous to slightly floccose streaks along the internodes below the primary leaves. These streaks interrupt the otherwise feltlike tomentum.

The primary leaves are more or less appressed, linear-subulate, 0.5 to 1 cm long, and terminate in mucronate or spinose tips. Their vestiture is glabrate to sparsely floccose. The secondary leaves are linear-filiform to slightly clavate, 3 to 10 mm long, and glabrous. They terminate in blunt tips.

Flower heads are arranged in compact, corymb-like clusters terminating the branches. Four glabrous or canescent, lanceolate to obovate, involucral bracts subtend each head which contains four golden yellow to cream disc flowers. Slender, densely hairy achenes, 3 to 4 mm long, are produced. The achene hairs overlap and blend with the bristly pappus, but do not obscure it.

The flowering pattern of this species is just the opposite of gray horsebrush. Little-leaf horsebrush begins flowering first during late April in the southern part of its range in the Mohave Desert and progresses northward to Idaho where it flowers in mid-June (Strother 1974). Seeds on the average are slightly larger than those of *T. canescens*.

Hybridization.--Tetradymia glabrata resembles *T. canescens* in being a polyploid species. Populations of this species with diploid ($2n = 60$) and hexaploid ($2n = 180$) numbers have been found. Sporadic aneuploid-diploid ($2n = 62$) individuals occur (Strother 1974).

Distribution and habitat.--Little-leaf horsebrush is most abundant in the sagebrush desert of the Great Basin but is found scattered in dry open places in foothills associated with sagebrush, creosote (*Larrea tridentata*), Joshua trees (*Yucca brevifolia*), and pinyon and juniper trees from eastern Oregon and western Idaho southward to northeastern California, Nevada, and Utah between 800 and 2,400 meters (2,600 and 8,000 feet). Its type locality is reported as the Sierra Nevada (Abrams and Ferris 1960).

Use.--Tetradymia glabrata is not ordinarily palatable to livestock. However, on overgrazed, depleted rangelands where more desirable browse is not available, this plant may be consumed. If large enough quantities are eaten in the spring when plants are most toxic, poisoning may result.

Johnson (1974a) reported an extremely variable hepatotoxic response of sheep to *T. glabrata* and found that plants in the same stage of development from different localities varied in their toxicity. This variation should allow use of less toxic, more palatable forms that may have potential use in revegetation of the harsh, arid sites where *Tetradymia* grows. Johnson (1974b) stated that prior consumption of *Artemisia* species (*A. nova* and *A. tridentata*) might be necessary for expression of toxic effects of *T. glabrata* (bighead/photosensitization).

Tetradymia nuttallii Torr. & Gray (Nuttall horsebrush)

This species is a rigidly branched, spiny shrub to 12 dm high. Its young stems are woolly-canescent with glabrescent streaks along the internodes below the spines (primary leaves). The stems become glabrate in age.

The primary leaves transform into straight or recurved spines 0.5 to 2.5 cm long (fig. 61). The sparsely tomentose to nearly glabrous spatulate, secondary leaves are 1 to 2 cm long and are borne in fascicles in the axils of the spines.

Heads containing 4 bright yellow disc flowers each are arranged into terminal, compact, corymb-like clusters. Four linear-oblong involucral bracts 4 to 8 mm long subtend each head. The densely white-hirsute to tomentose achenes are 4 to 6 mm

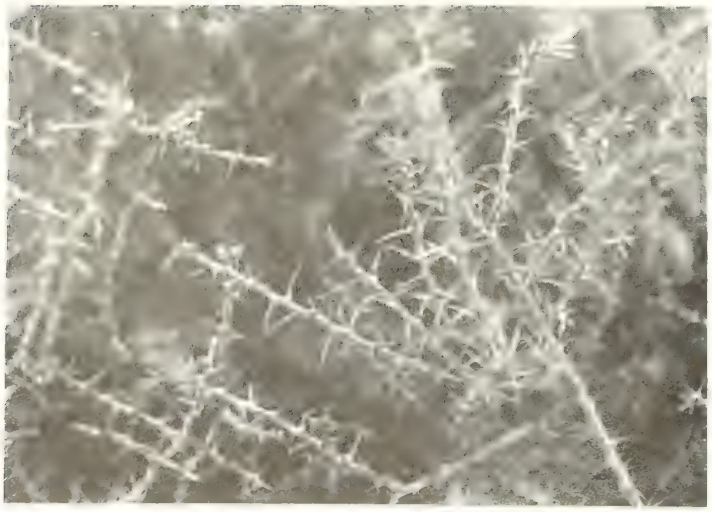

Figure 61.--Spines (arrow) on Nuttall horsebrush (T. nuttallii). Specimen growing in Antelope Valley, Sanpete Co., Utah.

long. Blooming occurs from late May to early July. Seeds are about 50 percent larger than those of *T. canescens*.

Hybridization.--Only diploid ($2n = 60$) populations have been reported for *T. nuttallii* (Strother 1974).

Distribution and habitat.--Nuttall horsebrush occurs in the badlands of southwestern Wyoming and in dry barren hills and plains of northeastern Nevada, northern half of Utah, and northwestern Colorado between 1,300 and 2,100 meters (4,300 and 6,900 feet) in elevation. It is usually associated with sagebrush and shadscale vegetational types.

Use.--The spiny growth habit precludes much use by animals except for cover. It contributes to the vegetal cover in dry, hostile environments.

Tetradymia spinosa Hook. & Arn. (spiny horsebrush[9])

Spiny horsebrush is a compact or spreading, much-branched spiny shrub to 12 dm high. Unlike the other horsebrushes mentioned in this paper, the dense, evenly pannose vestiture of the young stems is uninterrupted by streaks and is persistent as the stems age.

The primary leaves transform into stiff recurved spines 5 to 20 mm long. Fascicles of essentially glabrous, linear to narrowly spatulate, secondary leaves 3 to 15 mm long develop in the axils of the spines.

Flowering heads are produced singly or in pairs on short peduncles 1 to 1.5 cm long in the spine (primary leaf) axils formed the previous year. The heads usually contain 6 pale to bright yellow disc flowers. Five or 6 oblong to ovate, conspicuously tomentose, involucral bracts 8 to 12 mm long subtend each head. The achenes are covered with long white woolly hairs that more or less conceal the pappus of small, white, slender scales. Blooming normally occurs during May and June, but may extend into August.

Hybridization.--Only diploid ($2n = 60$) populations of *T. spinosa* have been reported (Strother 1974).

[9]Other common names include cottonthorn horsebrush and catclaw horsebrush.

Figure 62.--Flower head of snakeweed (X. sarothrae) illustrating ray flowers [illegible], Co., Utah.

Distribution and habitat.--This species is scattered throughout the Great Basin and adjacent areas from southwestern Montana across Idaho to southeastern Oregon and southward to northwestern New Mexico, Utah Nevada, and eastern California. In these areas, spiny horsebrush occurs at elevations of 850 to 2,400 meters (2,800 to 7,900 feet) in alkali sinks, and in shadscale, sagebrush, creosote, pinyon-juniper, and yellow pine vegetational types.

Use.--Like Nuttall horsebrush, spiny horsebrush is of little direct use to animals because of its growth habit. It does provide cover for smaller animals and is a useful soil stabilizer where it grows.

CHARACTERISTICS OF THE GENUS *XANTHOCEPHALUM*[10] (MATCHBRUSH, SNAKEWEED)[11]

This genus consists of perennial herbs and low suffrutescent shrubs (subshrubs) with woody roots, crowns, and stem bases. Its leaves are entire, linear to narrowly oblanceolate, and usually sticky from resin exuded to the surfaces of both leaves and young stems.

Numerous small heads form in loose or crowed terminal clusters. Resinous, imbricated involucral bracts with thin membranous margins and green tips subtend each head. A few yellow ray and disc flowers are both present (fig. 62). The ray flowers are usually pistillate and fertile while the disc flowers are usually perfect and fertile or sometimes staminate. Pappi of several small scales or awns are generally present, at least on the disc flowers. Achenes are small, oblong or obovoid, and pubescent. Blooming occurs from May to October.

The basic chromosome number for *Xanthocephalum* is x = 4 (Solbrig 1971; Pinkava and Keil 1977).

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[10]This genus has long been known as *Gutierrezia* (Ruffin 1974).

[11]Other common names include matchweed, perennial snakeweed, broom snakeweed, broomweed, resinweed, stinkweed, turpentine weed, and yellow top.

The numerous common names for this genus are perhaps indicative of its wide distribution. The genus consists of about 25 species scattered throughout western North and South America. Only two of these species, *X. sarothrae* and *X. microcephala*, are of importance in the Intermountain area. Other North American species include *X. bractereata*, *X. californica*, and *X. serothina*.

Matchweed commonly invades depleted ranges and is considered an indicator of overgrazed rangelands. Species in this genus are generally unpalatable and seldom grazed. When eaten in quantity, this plant is more or less poisonous to sheep and goats (Benson and Darrow 1944; Kearney and Peebles 1960).

Xanthocephalum microcephala Shinners (small headed matchweed[12])

Small-headed matchweed is a many-stemmed subshrub up to 6 dm tall. Its stems and leaves are glabrous and resinous. The leaves are linear-filiform and usually less than 1 mm wide.

Tiny heads, only 3 mm long and 1 to 1.5 mm wide, occur singly or are more often arranged in small terminal cyme-like clusters. The heads commonly have 1 to 3 disc flowers. Involucral bracts with yellow tips and prominent hyaline margins surround the heads.

Hybridization.--Some authors consider *X. microcephala* to be a subspecies or variety of *X. sarothrae* (Benson and Darrow 1944; Harrington 1954). This species forms a polyploid series with chromosome numbers of $2n = 16$, 24, and 32 (Solbrig 1971; Keil and Pinkava 1976).

Distribution and habitat.--This species occurs between 1,000 and 2,500 meters (3,300 and 8,200 feet) in elevation from Idaho southward to southeastern California, Arizona, New Mexico, Texas, and on into Mexico. It may be associated with the sagebrush, pinyon-juniper, yellow pine, and aspen vegetational types. Type locality is reported as "Saltillo, Mexico" (Abrams and Ferris 1960).

Use.- Xanthocephalum microcephala has poisoned large numbers of sheep and cattle under range conditions in Texas. It may cause death in acute cases, but abortion is more commonly the result of poisoning by this species. As long as the animals can find, or are provided with, sufficient supplementary forage, poisoning usually does not occur (Kingsbury 1964).

Xanthocephalum sarothrae Shinners (broom snakeweed)

Broom snakeweed is a subshrub up to 7 dm tall (fig. 58). It has a deep taproot, extensive lateral roots, and a woody crown from which grow numerous, slender, erect, brittle, essentially herbaceous branches. The branches and leaves are green, glabrous to puberulent, and slightly resinous. The leaves are also punctate, linear, 2 to 5 cm long, and 1 to 2 mm wide.

The heads contain from 3 to 8 ray and disc flowers each. Resinous, often green-tipped involucral bracts are arranged in a series of 2 to 4 rows around each head and many appear to be in somewhat vertical ranks. The bracts are 3 to 6 mm long and 2 to 3 mm wide. Blooming occurs from May to October. Broom snakeweed has 3,535 seeds per gram (1,605,000 seeds per pound).

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[12]Also known as thread-leaf matchweed.

Hybridization.--*Xanthocephalum sarothrae* has a basic chromosome number of $x = 4$. It is a polyploid species consisting most commonly of diploid ($2n = 8$) and occasionally of tetraploid ($2n = 16$) populations. Both the diploids and the tetraploids show considerable variation and grow intermixed through the range of species (Harrington 1954; Solbrig 1971; Pinkava and Keil 1977).

Distribution and habitat.--Broom snakeweed is the most abundant snakeweed in western North America. Many ecotypes have been found. It occurs in plains, valleys, foothills, and mountainsides from Saskatchewan and Alberta to southeastern Washington, southward to Texas and Baja California. It grows in a wide range of soil types at elevations between 900 and 3,000 meters (2,950 and 9,850 feet) and may be associated with such plants as creosote bush, mesquite (*Prosopis* spp.), soapweed (*Yucca* spp.), rabbitbrush, big sagebrush, black sagebrush, shadscale, pinyon-juniper, oak (*Quercus* spp.), Indian ricegrass (*Oryzopsis hymenoides*), grama grass (*Bouteloua* spp.), buffalo grass (*Buchloe dactyloides*), and cheatgrass (*Bromus tectorum*) (USDA Forest Service 1937).

The type locality of *X. sarothrae* is listed as the "plains of Missouri River" (Abrams and Ferris 1960).

Use.--This shrub is a very aggressive invader into areas where the climax vegetation has been depleted. It is considered an indicator of range deterioration because it is one of the first plants to invade when the range has been overgrazed and often becomes the principal plant cover. As such, it is important in protecting the soil against erosion. Broom snakeweed has usefulness as a pioneer shrub on other types of disturbed areas as well. It is not, however, competitive with other perennial cover.

Throughout its range, *X. sarothrae* is generally considered as poor forage and is grazed mainly because of lack of anything better. It is a secondary or facultative selenium absorber (Kingsbury 1964), and heavy use by livestock may cause sickness and death where it takes up this chemical. On many areas it is substantially browsed by livestock and game without any obvious ill effects. On the winter ranges of western Utah and eastern Nevada, this shrub is rated as fair forage of sheep which browse it most heavily after growth begins in the spring (USDA Forest Service 1937).

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APPENDIX

Compositae — Key to genera and species

1a. Head with both ray and disc flowers; pappus of several to many scales ..... *Xanthocephalum* 63
(matchbrush, snakeweed)

2a. Leaves linear-filiform, less than 1 mm wide; heads tiny, cylindrical, 1 to 1.5 mm thick; ray flowers 4 to 5; disc flowers 1 to 3..... *X. microcephala* 64
(small-headed matchweed)

2b. Leaves linear, 1 to 2 mm wide; heads larger, flaring; ray flowers 3 to 9, disc flowers 3 to 8..... *X. sarothrae* 64
(broom snakeweed)

1b. Heads with only disc flowers or if ray flowers present then pappus of capillary bristles or lacking.

3a. Pappus of capillary bristles, at least in part.

4a. Involucral bracts in a single series..... *Tetradymia* 58
(horsebrush)

5a. Stem vestiture evenly pannose; primary leaves forming rigid spreading or recurved spines; flowers 5 to 9 per head; involucral bracts 5 to 6; heads solitary or paired in upper axils; achenes with abundant long hairs that obscure the pappus; pappus of small scales.... *T. spinosa* 62
(spiny horsebrush)

5b. Stem vestiture interrupted by linear streaks; spines, if present, not spreading; flowers 4 per head; involucral bracts usually 4; heads arranged in corymbose clusters at ends of branches; achenes glabrous or with hair shorter than the pappus; pappus of numerous bristles.

6a. Primary leaves forming rigid spines..*T. nuttallii* 61
(Nuttall horsebrush)

6b. Primary leaves not forming rigid spines, but may be spinulose-tipped.

7a. Primary leaves linear-subulate, 0.5 to 1 cm long, mucronate or spinulose-tipped; herbage often becoming glabrate..... *T. glabrata* 60
(little-leaf horsebrush)

7b. Primary leaves linear-lanceolate to spatulate, 1 to 3 cm long, not mucronate or spinulose-tipped; herbage permanently canescent or tomentose..... *T. canescens* 59
(gray horsebrush)

4b. Involucral bracts of 2 or more series..... *Chrysothamnus* 36
(rabbitbrush)

8a. Twigs glabrous or finely puberulent. *Page No.*

9a. Flowers white; leaves glabrous with copius resinous exudate, surface with small pits; alkaline areas from western Utah to eastern California... *C. albidus* (alkali rabbitbrush) 39

9b. Flowers pale to dark yellow; leaves not as above.

10a. Achenes glabrous, or glandular only at distal end.

11a. Involucral bracts 5 to 7 mm long, with thick greenish apical tips, not strongly alined into ranks..... *C. vaseyi* (Vasey rabbitbrush) 53

11b. Involucral bracts 10 to 13 mm high, lacking thick greenish apical tips, strongly alined into 5 vertical ranks..... *C. depressus* (dwarf rabbitbrush) 39

10b. Achenes densely pubescent.

12a. Involucral bracts with narrowly acuminate, greenish tips..... *C. greenei* (Greenes rabbitbrush) 41

12b. Involucral bracts acute to obtuse.

13a. Heads somewhat turbinate, 5 to 6 flowered, shrubs large, up to 2.4 m tall; leaves 4 to 8 mm wide; involucral bracts thick with conspicuous green spots near obtuse apex... *C. linifolius* (spreading rabbitbrush) 42

13b. Heads narrowly cylindric, 3 to 5 flowered; shrubs various; leaves often twisted, 1 to 6 mm wide ..... *C. viscidiflorus* complex (low rabbitbrush) 54

14a. Leaves and upper stems glabrous.

15a. Shrubs usually over 5 dm tall, leaves 1 to 5 mm wide, 2 to 5 cm long; usually with very pungent odor..... *C. viscidiflorus* ssp. *viscidiflorus* (stickyleaf low rabbitbrush) 57

15b. Shrubs less than 5 dm tall; leaves 1 mm wide, 1 to 3 cm long, filiform; odor various ..... *C. viscidiflorus* ssp. *stenophyllus* (narrowleaf low rabbitbrush) 57

14b. Leaves and upper stems pubescent. *Page No.*

16a. Leaves 2.5 to 6 mm wide, 1.5 to 4 cm long; involucral bracts without thickened greenish spot near tip; common in mountains and upper foothills ..... *C. viscidiflorus* ssp. *lanceolatus* 56
(mountain low rabbitbrush)

16b. Leaves up to 2 mm wide, 3 cm long; involucral bracts often with thickened greenish spot near tips; occurs on dry plains, valleys, and foothills ..... *C. viscidiflorus* ssp. *puberulus* 57
(hairy low rabbitbrush)

8b. Twigs with often densely compacted tomentum or at least tomentose.

17a. Bracts very attentuate; inflorescence mostly racemose..... *C. parryi* complex 51
(Parry rabbitbrush)

18a. Flowers 10 or more per head..... *C. parryi* ssp. *parryi* 53
(Parry rabbitbrush)

18b. Flowers 9 or less per head.

19a. Inflorescence of single or paired heads..... *C. parryi* ssp. *monocephalus* 53

19b. Inflorescence racemose of several to many heads.

20a. Leaves with short-stalked resin glands..... *C. parryi* ssp. *asper* 52

20b. Leaves lacking stalked resin glands.

21a. Upper leaves longer than inflorescence; flowers 8 to 10 mm long, pale yellow..... *C. parryi* ssp. *howardi* 52
(Howard rabbitbrush)

21b. Upper leaves shorter than inflorescence; flowers 9 to 12 mm long, clean yellow.

Page No.

22a. Bracts with straight tips; heads 11 to 15 mm long ..... *C. greenei* ssp. *[illegible]*

22b. Bracts with recurved tips; heads 14 to 19 mm long ..... *C. [illegible]* ssp. *nevadensis* 53
(Nevada rabbitbrush)

17b. Bracts acute to obtuse; inflorescence mostly cymose ..... *C. [illegible]* complex 43
(rubber rabbitbrush)

23a. Leaves usually grayish-white; involucral bracts puberulant or tomentose.

24a. Leaves 3 to 10 mm wide, 4 to 8 cm long; bracts mostly obtuse..... *C. nauseosus* ssp. *salicifolius* 47
(mountain rubber rabbitbrush)

24b. Leaves 3 mm or less wide, 2.5 to 4 cm long; bracts mostly acute..... *C. nauseosus* ssp. *albicaulis* 45
(white rubber rabbitbrush)

23b. Leaves usually greenish-yellow; involucral bracts glabrous.

25a. Leaves 1 to 3 mm wide, 4 to 6 cm long; mildly ill-scented..... *C. nauseosus* ssp. *graveolens* 47
(green rubber rabbitbrush)

25b. Leaves less than 1 mm wide 2.5 to 5 cm long; strongly disagreeable odor..... *C. nauseosus* ssp. *consimilis* 46
(threadleaf rubber rabbitbrush)

Page No.

3b. Papus lacking..... *Artemisia* (sagebrush) 3

26a. Heads with both ray (marginal) flowers and disc flowers; plants subshrubs or shrubs.

27a. Plants subshrubs; leaves 2 or 3 times pinnately parted, silky-canescent; widely distributed through western North America, Siberia, northern Asia, and Europe..... *A. frigida* (fringed sagebrush) 13

27b. Plants shrubs; leaves not as above.

28a. Branches spinescent; leaves 3 to 5 palmately parted with segments 3-lobed, white tomentose, deciduous; occurs on dry, saline plains and hills from northwestern Montana west to eastern Oregon and south to California, Arizona, and New Mexico..... *A. spinescens* (bud sagebrush) 24

28b. Branches not spinescent; leaves not as above.

29a. Leaves filiform, entire or ternately divided into filiform segments, silvery-white canescent; heads with 2 to 3 ray flowers and 1 to 6 disc flowers; occurs mostly in sandy soil from Nevada east to western Nebraska and south to Texas, Arizona, and Chihuahua..... *A. filifolia* (sand sagebrush) 12

29b. Leaves narrowly cuneate, mostly finely tridentate, silvery-canescent; heads smaller with 0 to 2 ray flowers and 1 to 3 disc flowers; occurs in canyons, gravelly draws, and dry flats from western Texas to California..... *A. bigelovii* (Bigelow sagebrush) 9

26b. Heads with disc flowers only; plants shrubs.

30a. Plants up to 5 dm high.

31a. Plants dwarf, less than 2 dm high.

32a. Plants depressed, cushionlike shrubs; leaves 2 to 8 mm long, pinnately divided into 3 to 11 lobes; limited to calcarious desert soils, central and western Utah, central and eastern Nevada, and northern Arizona..... *A. pygmaea* (pigmy sagebrush) 19

Page No.

32b. Plants with decumbent, frequently layering branches; leaves often 3 cm long, deeply cleft into 3 linear lobes; rocky knolls from 2,430 to 2,740 m in central and southeastern Wyoming to southern Oregon..... *A. tripartita* ssp. *rupicola* 35
(Wyoming threetip sagebrush)

31b. Plants low from 2 to 5 dm high (but may be less).

33a. Heads axillary and sessile, generally all surpassed by their subtending leaves; leaves deeply divided into 3 to 5 narrowly linear lobes; deciduous ..... *A rigida* 20
(stiff sagebrush)

33b. Heads usually in branched racemose panicles or if spikelike, then subtending leaves do not surpass heads; leaves 3- to 5-toothed or lobed, cuneate to fan-shaped, persistent.

34a. Leaves broadly cuneate, deeply 3-lobed involucre broadly companulate; flower heads 3 to 5 mm broad with 6 to 11 disc flowers; blooming begins in mid-June; seeds 2.5 mm long, ripening in August; adapted to heavy, highly impermeable, alkaline soils from 1,800 to 2,450 m from southwestern Montana to northwestern Colorado, Utah, Nevada, Idaho, and Oregon ..... *A* [illegible] 16
(alkali sagebrush)

34b. Leaves cuneate to broadly cuneate or fan-shaped, 3- to 5-toothed or cleft; involucre narrowly campanulate; flower heads and seed smaller than above; blooming normally occuring later than July; seed ripen late September and October.

35a. Leaves cuneate, 3-toothed (upper leaves may be entire), viscid; heads arranged in narrow spikelike panicles; disc flowers 3 to 5 per head; corollas 1.8 to 3 mm long; involucral bracts glabrous or nearly so; plants usually dark green with persistent red-brown inflorescent stalks; occurs on dry, shallow, rocky soil between 1,500 and 2,400 m in most western States ..... *A.* [illegible] 17
(black sagebrush)

35b. Leaves broadly cuneate or fan-shaped, 3- to 5-toothed or cleft (upper leaves may be entire), not viscid; heads arranged in narrow racemose panicles; disc flowers 5 to 11 per head; corollas 3 to 4 mm long; involucral bracts canescent; plant usually lighter in color than above; distribution similar to *A. nova* but offset to the northwest, usually found at somewhat higher elevations in more moist habitats than *A. nova*..... *A. arbuscula* (low sagebrush) 6

30b. Plants usually over 5 dm high (39b and 42b provide most exceptions to 5 dm height).

36a. Leaves silvery-canescent, linear to linear-oblanceolate, mostly entire (occasionally with a few irregular teeth), or leaves deeply divided into 3 or more linear or linear-oblanceolate lobes.

37a. Leaves entire or occasionally with 1 or 2 irregular teeth or lobes..... *A. cana* (silver sagebrush) 10

38a. Leaves 2 to 8 cm long, 1 to 10 mm wide, densely silky-canescent; heads arranges into dense leafy panicles; occurs mostly east of the Continental Divide from southern Canada to northern Colorado..... *A. cana* ssp. *cana* (silver sagebrush) 12

38b. Leaves smaller than above (up to 7 cm long, 1 to 5 mm wide) and often crowded into dark-green clusters; heads arranged into dense, short raceme or spikelike inflorescences; occurs mostly west of the Continential Divide from southwestern corner of Montana to Arizona and New Mexico ..... *A. cana* ssp. *viscidula* (mountain silver sagebrush) 12

37b. Leaves typically deeply divided into 3 linear or narrowly lanceolate lobes which in turn may be 3-cleft..... ..... *A. tripartita* (threetip sagebrush) 34

39a. Plants freely branching, shrubs up to 2 m; leaves 1.5 to 4 cm long, deeply divided into 3 linear lobes, each less than 1 mm wide; occurs on dry, well drained soils from [illegible] to 1,[illegible] m from British Columbia south to northern Nevada, northern Utah, and western Montana..... *A. tripartita* ssp. [illegible]
(tall threetip sagebrush)

39b. Plants dwarf shrubs with decumbent, often layering branches; leaves up to 3 cm long, deeply divided into linear lobes 1 mm or more wide; occurs on rocky knolls from 2,430 to 2,740 m in central and southeastern Wyoming to southern Oregon ..... ssp. [illegible]
(Wyoming threetip sagebrush)

36b. Leaves not silvery-canescent, narrowly lanceolate to broadly cuneate or fan-shaped, typically 3-toothed or lobed (upper leaves may be entire).

40a. Plants low-growing, flat-topped shrubs up to 8 dm high; leaves somewhat viscid; heads occurring singly or occasionally up to 3 arranged in short interrupted spike or racemelike inflorescences; heads large with up to 20 disc flowers each; occurs in high mountainous areas of central Colorado, western Wyoming, Utah, central Sierras of California, and Carson Range of Nevada..... *A. rothrockii* 23
(timberline sagebrush)

40b. Plants ranging from dwarf to tall, arborescent forms up to 4.5 m; leaves not viscid; inflorescences of numerous heads arranged into leafy panicles; heads smaller with 3 to 8 disc flowers; most widespread and common shrub of western North America..... [illegible]
(big sagebrush)

41a. Plants uneven-topped shrubs with flowering stalks arising throughout the crown; leaves narrowly lanceolate to cuneate; odor of crushed leaves pungent.

42a. Mature plants often arborescent (with single trunklike main stem), usually from 1 to 2 m but in some forms up to 4.5 high; leaves narrowly lanceolate with margins not curving outward; average persistent 5.6 times its width; blooming starts in late August or September; odor strongly pungent; normally occurs below 2,100 m in dry deep, well-drained soils on plains, valleys, and foothills ..... *A. tridentata* ssp. *tridentata* (basin big sagebrush) 30

42b. Mature plants with several main branches usually less than 1 m high; leaves narrowly cuneate to cuneate with margins curved outward; average persistent leaf length is 3.1 times its width; blooming starts in late July or August, odor pungent; occurs on dry, shallow, gravelly soil from 1,500 to 2,100 m ..... *A. tridentata* ssp. *wyomingensis* (Wyoming big sagebrush) 33

41b. Plants usually even-topped shrubs with flower stalks arising from upper crown portions; leaves broadly cuneate to spatulate; average persistent leaf length is 4.0 times its width; blooming may begin in July; odor slightly pungent to pleasantly mintlike; occurs from 1,400 to 3,000 m in deep well-drained soils..... *A. tridentata* ssp. *vaseyana* (mountain big sagebrush) 31

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Artemisia are presented.

KEYWORDS: distribution, hybridization, composite shrubs, habitat, use,

Stevens.

Reviews the state of knowledge, record observation , and pre ent original data for important Intermountain composite shrub . A] c , t given to and recognition of taxa. Each species treated is described and its hybridization, distribution and habitat, use, and subspecies are reviewed. Results of hybridization experiments in section Tridentatae of Artemisia are presented.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

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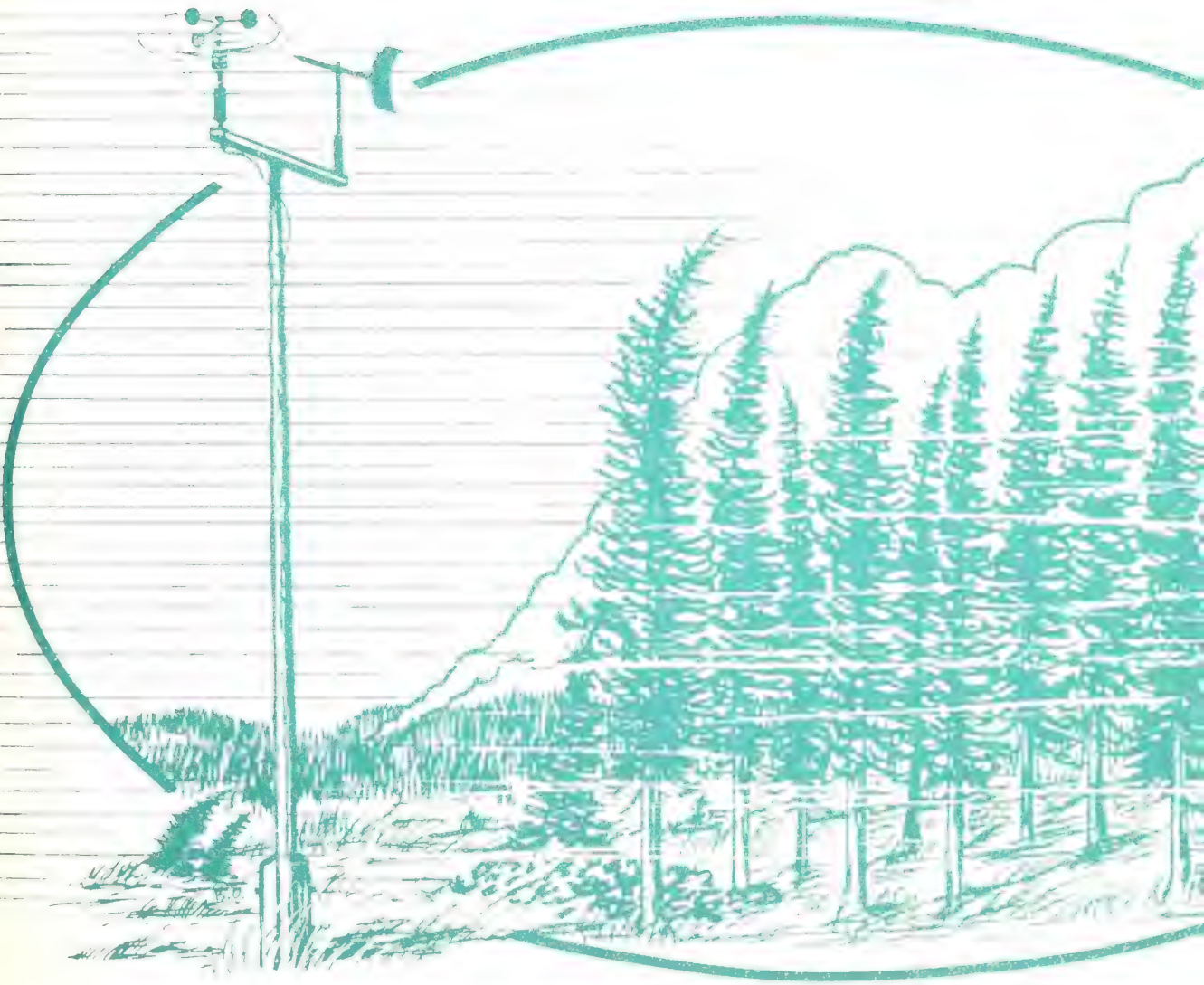
ESTIMATING WINDSPEEDS FOR PREDICTING WILDLAND FIRE BEHAVIOR

F.A. ALBINI AND R. G. BAUGHMAN



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RESEARCH SUMMARY

This paper presents formulae, tables, and figures that can be used to estimate the ratio of mean windspeed acting on the flame from a prescribed wildland fire to the mean windspeed 20 ft (6 m) above the vegetation cover. The formulae are based upon the logarithmic windspeed variation law characteristic of neutral shear turbulent flow, and are restricted to flat terrain with uniform, continuous vegetation cover.

By equating integrated bulk drag due to crown foliage to the shear stress at the top of the crown layer, a model for relating windspeed within and below a uniform forest canopy to windspeed 20 ft (6 m) over the canopy is developed. Important variables in this model include stand height, crown closure, foliar surface/volume ratio, and crown bulk density. Comparison of model predictions with reported experimental measurements shows good agreement.

CONTENTS

	Page
INTRODUCTION	1
LOGARITHMIC WIND PROFILE	1
WINDSPEED AT THE TOP OF THE VEGETATION COVER	3
GENERAL USE OF THE LOGARITHMIC WIND PROFILE EQUATION	6
WIND UNDER A CANOPY	6
COMPARISON WITH MEASUREMENTS	10
APPLICABILITY OF RESULTS	11
PUBLICATIONS CITED	12

INTRODUCTION

Presented here is a means of estimating the windspeed over various wildland fuel types from the "standard" windspeed [illegible]. The report is divided into two major sections. The first deals with the wind above a vegetative canopy, over that is a single-stratum fuel (grass, brush, etc.). The second part deals with the wind under a forest canopy. The windspeed at the top of the canopy is [illegible] use of a logarithmic wind profile. Sandpatil [illegible] estimates the canopy-top value by use of a model based on mechanical force balance.

This research report deals only with the steady, undisturbed windfield and its influence on fire in surface fuels. No account is taken of the influence of the fire on the windspeed, wind direction, or the profile of windspeed with height. Furthermore, flat terrain and uniform continuous vegetation cover are assumed.

These restrictions clearly limit the applicability of the results, but even the extent and severity of the restrictions is uncertain. Rothermel's model implicitly accounts for local (near-flame) influence of the fire on the windfield. At what intensity or size the fire's influence on the [illegible] can only be estimated by order-of-magnitude arguments at present. Future research should help to clarify this situation.

The restriction to flat terrain can probably be relaxed to "smooth" or "slightly uneven" terrain, but numerical descriptions of adequate "flatness" are not presently available. Similar considerations apply to the uniformity and continuity of vegetation cover required, and these matters are under study in the field of applied meteorology (Bergen 1976).

With these restrictions in mind, the [illegible] direction of a more complete description of the complex phenomena with which we are dealing.

LOGARITHMIC WIND PROFILE

The windspeed above a vegetative cover was determined by using the logarithmic wind profile in the following form (Sutton 1953, p. 239):

$$U_z = \frac{U_*}{K} \ln\left(\frac{z-D_0}{z_0}\right)$$

where

$\overline{U}_z$ is the average windspeed at height z

U_* is the friction velocity ($U_* = \sqrt{\tau/\rho}$, τ is the horizontal shear stress and ρ is air density)

K = 0.4 (the von Kármán constant)

z is height above ground

D_o is the zero-plane displacement

z_o is the roughness length.

The values for D_o and z_o were taken from the works of Cowan (1968) and Stanhill (1969). Figure 1, taken from Stanhill, shows a plot of D_o versus vegetation height. The plot agrees with the relationship $D_o = 0.64H$ derived by Cowan, where H is the vegetation height. The derived relationship was based on $z_o = 0.13H$ as found by Tanner and Pelton (1960).

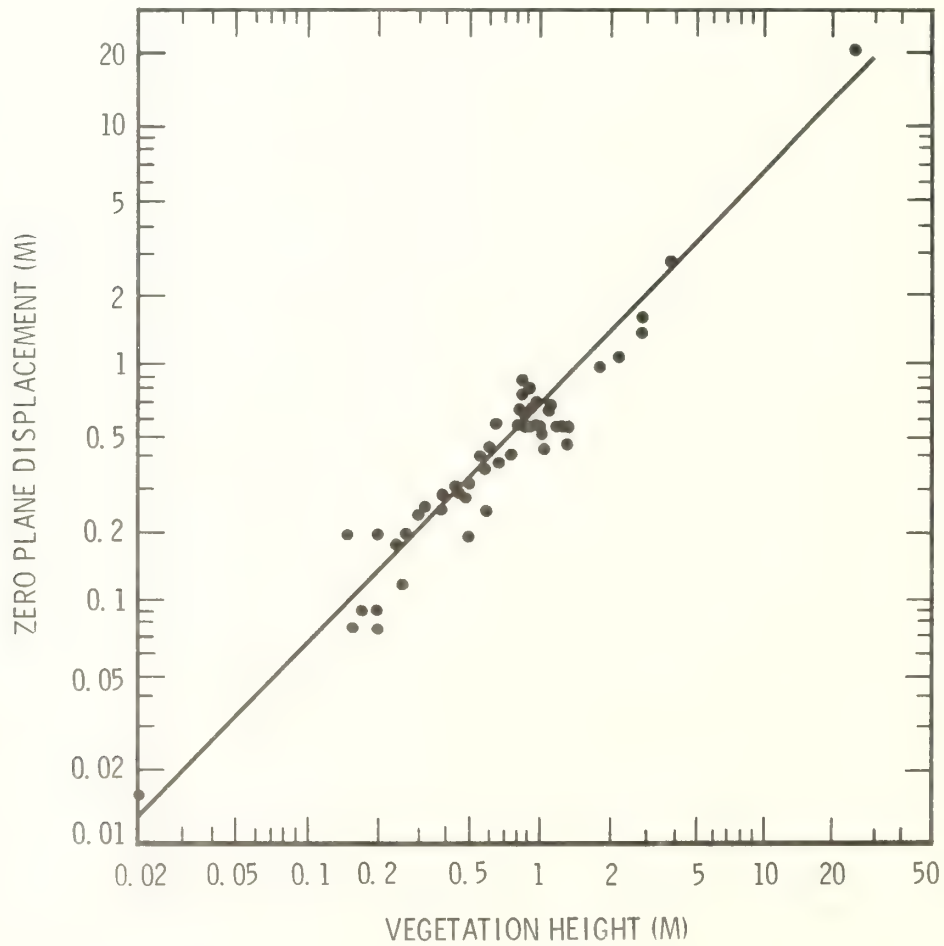


Fig. 1.--Relationship between zero-plane displacement D_o and vegetation height H for different vegetation types (after Stanhill 1969).

WINDSPEED AT THE TOP OF THE VEGETATION COVER

WINDSPEED FOR PREDICTING FIRE SPREAD IN SURFACE FUEL (NO CANOPY CASE)

Consider an average windspeed over the height range H to H + H_F, where H_F is the extension of the flame above the fuel bed.

$$\bar{U} = \frac{1}{H_F}\int_{H}^{H+H_F} U\,dz = \frac{1}{H_F}\,\frac{U_*}{K}\int_{H}^{H+H_F} \ln\left(\frac{z-D_o}{z_o}\right) dz \tag{5}$$

let $x = \left(\frac{z-D_o}{z_o}\right)$

$$\frac{z_o}{H_F}\,\frac{U_*}{K}\int_{a}^{b} \ln x\,dx = \frac{z_o}{H_F}\,\frac{U_*}{K}\; x\,(\ln x - 1)\Big|_{a}^{b}$$

$$\bar{U} = \frac{z_o}{H_F}\,\frac{U_*}{K}\left(\frac{z-D_o}{z_o}\right)\left[\ln\left(\frac{z-D_o}{z_o}\right) - 1\right]\Bigg|_{H}^{H+H_F} \tag{6}$$

Note that at the lower limit (H) the value is nearly zero since:

$$\ln\left(\frac{H-0.64H}{0.13H}\right) \cdot 1 \tag{7}$$

Thus we find

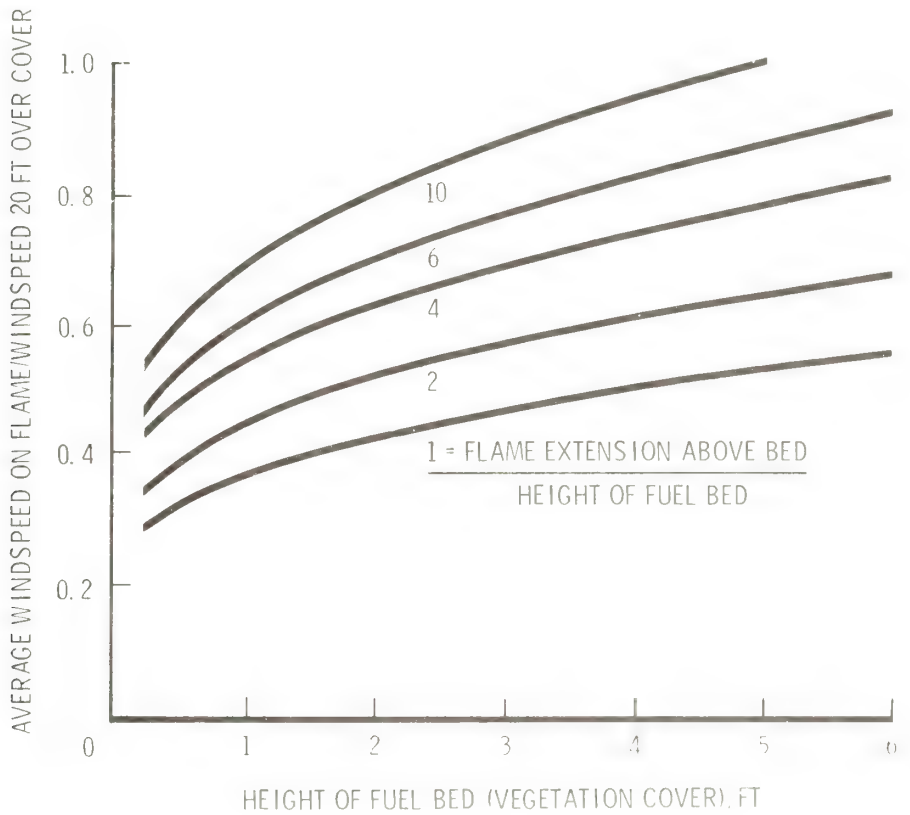
$$\bar{U} = \frac{U_*}{K}\,\frac{H + H_F - 0.64H}{H_F}\left[\ln\left(\frac{H + H_F - 0.64H}{0.13H}\right) - 1\right]$$

$$= \frac{U_*}{K}\left(1 + 0.36\,\frac{H}{H_F}\right)\left[\ln\left(\frac{H_F/H + 0.36}{0.13}\right) - 1\right] \tag{8}$$

Values of F can be calculated for [illegible] fuels. Using equation (7), see [illegible]:

$$\frac{U}{U_{20+H}} = \frac{1 + 0.36H/H_F}{\ln\left(\frac{20 + 0.36H}{0.13H}\right)}\left[\ln\left(\frac{H_F/[illegible]}{[illegible]}\right) - 1\right]$$

The graph of figure 2 can be used to establish the ratio of the "midflame" windspeed to the windspeed 20 ft over the vegetation cover for various fuel heights H and flame extensions H_F.



GENERAL USE OF THE LOGARITHMIC WIND PROFILE EQUATION

According to several authors, the log-wind profile represents the actual wind profile near the surface of the earth only under neutral stability condition. However, various researchers have found that the log-wind profile represents the wind above a vegetative cover (very rough surface) over a wide range of atmospheric conditions. For example, van Hylckama (1970) reports that a log-wind profile represented the wind variation above a salt cedar stand (*Tamarix pentandra*) for all his afternoon observations and for many night conditions. Of 744 data sets, only 84 were too irregular for log-wind representation. Oliver (1971) found the wind profile above a pine forest to be well described by the logarithmic form over a wide range of stability conditions.

Apparently, large temperature gradients cannot be maintained above a forest canopy due to air movement through the canopy (Munn 1966, p. 158) and due to mixing by which the wind blowing over a very rough surface reduces air temperature variations above the canopy. Thus extreme lapse or inversion temperature conditions are unlikely to obtain over a vegetative cover, resulting in a broad applicability of the log-wind profile. However, we advise that this form not be used to estimate winds under conditions of strong surface air temperature inversions. In summer this happens most often at night under clear skies with very low surface wind speeds. So when wind represents an important influence on fire behavior, the log profile usually is applicable.

WIND UNDER A CANOPY

To model the variation of windspeed with height for air flow through and under a forest canopy, we make several simplifying assumptions:

1. Below some height, z_M, near but below the top (height H) of the uniform forest canopy, the windspeed is approximately constant with height.

2. The foliage within the height range from z_M down to the bottom of the live crowns at height z_m provides a bulk drag force that resists the airflow.

3. Shear stress (equal to that in the constant stress layer above) on the surface $z = z_M$ balances the integrated bulk drag force in the constant speed layer.

The approximate windspeed profile is thus:

$$\bar{U}(z) = \begin{cases} (U_*/K) \ln\left(\dfrac{z - 0.64H}{0.13H}\right) & , \quad z \geq z_M \\ U_c & , \quad z \leq z_M \end{cases} \tag{10}$$

The assumption of a constant windspeed beneath the canopy seems quite reasonable according to various authors (Fons 1940, Geiger 1966, Shaw 1977). Now the resistance to airflow in the canopy can be expressed as a force/unit volume, R, due to drag on the canopy foliage (conifer needles in most applications). The value of R is given by:

$$R = \frac{1}{2} \rho U_c^2 \tilde{C}_D A_m, \tag{11}$$

here

ρ the air density

u wind speed in canopy

C_D the average drag coefficient

A the side view area of needle = ℓD (length · diameter)

n is the average number of needles per unit volume

$\beta = \frac{1}{2}$, the average

hus

$$\tau = \frac{1}{2}\rho C_D \sigma \beta u^2 \qquad (4)$$

here σ is the surface-area-to-volume ratio of a single needle. This bulk resistive orce, integrated over the height range z_m to z_M, provides the shear stress requirement τ) for the upper surface:

$$\tau = \tau_M (z_M - z_m) \qquad (5)$$

ince at z_M the shear stress is assumed to be that of the constant-shear layer, we have

$$\tau_M = \tau_*^2 \qquad (6)$$

nd so

$$\left(z_M - z_m\right) = \frac{\tau_*^2}{\tau} \qquad (7)$$

rom this last expression and equation (3) we find

$$\left(\frac{u}{u_*}\right)^2 = \frac{1}{\beta}\left(\frac{z_M - z_m}{\ell}\right) \qquad (8)$$

or a uniform stand of nearly identical trees we can replace $z_M - z_m$ by H·(CR) where H s tree height and CR is the crown ratio. Likewise, the average packing ratio, , an be expressed as

$$\beta = \beta F \qquad (9)$$

here β is the packing ratio for a single tree crown and F is the fraction of the canopy ayer filled with tree crowns. The fraction F is to be approximated by the product of rown closure and a fraction accounting for the tapering of crowns that results in addi- ional void volume higher in the canopy. Finally, the product of F and CR can be epresented by f, a fraction that represents the portion of volume under the canopy op that is filled with tree crowns.

Typical crown ratios[1] are displayed in table 1. The fraction of the canopy layer that is occupied by tree crowns (F above) we take to be 0.4 for dense stands and 0.1 for open stands. Table 2 gives the volume-filling fractions (f above) resulting from the products of the crown ratios of table 1 and these closure factors. In terms of the volume fraction, f, equation (17) provides a relationship for the windspeed under the canopy, U_c, and the windspeed at the top of the canopy, U_H:

$$U_c/U_H = K\left(2\pi/\tilde{C}_D\beta\sigma fH\right)^{1/2} \qquad (19)$$

Table 1.--*Typical crown ratios, percent*

Stand stocking	Shade-tolerant trees: Young	Shade-tolerant trees: Mature	Shade-intolerant trees: Young	Shade-intolerant trees: Mature
Dense	80	60	40	20
Open	90	70	70	50

Table 2.--*Volume filling fractions (factor f), percent*

Stand stocking	Tolerant: Young	Tolerant: Mature	Intolerant: Young	Intolerant: Mature
Dense	32	24	16	8
Open	9	7	7	5

This expression can be reduced to a simpler form by using nominal numerical values for the parameters that are essentially constant. The value of K can be taken as 0.4, $\tilde{C}_D$ is approximately 1.0 (Schlichting 1968), and the product $\beta\sigma$ can be treated as a constant[2] equal to 3.26 ft^{-1}. So for H measured in feet,

$$\frac{U_c}{U_H} = K\sqrt{\frac{2\pi}{\tilde{C}_D\beta\sigma fH}} = 0.4\sqrt{\frac{2\pi}{(1)(3.26)\,fH}} = \frac{0.555}{\sqrt{fH}} \qquad (20)$$

Values of U_c/U_H for three tree heights are given in table 3, based on the f values of table 2.

[1] The authors are indebted to Dr. James K. Brown of the Northern Forest Fire Laboratory for providing these typical quantities.

[2] This is an average value for 10 Rocky Mountain conifers. Data were taken from study material by J. K. Brown (on file at NFFL, Missoula) used in establishing crown foliage weight relationships (see Brown 1976). The standard deviation of the product $\beta\sigma$ for these species is 1.08 ft^{-1}.

Table 3.--

Stocking level	Tolerant species			Intolerant		
	Young 40'	Mature 100'	Pacific 180'	Young 40'	Mature 100'	Pacific 180'
Dense	0.155	0.113	0.084	0.220	0.196	0.146
Open	0.293	0.210	0.156	0.332	0.248	0.185

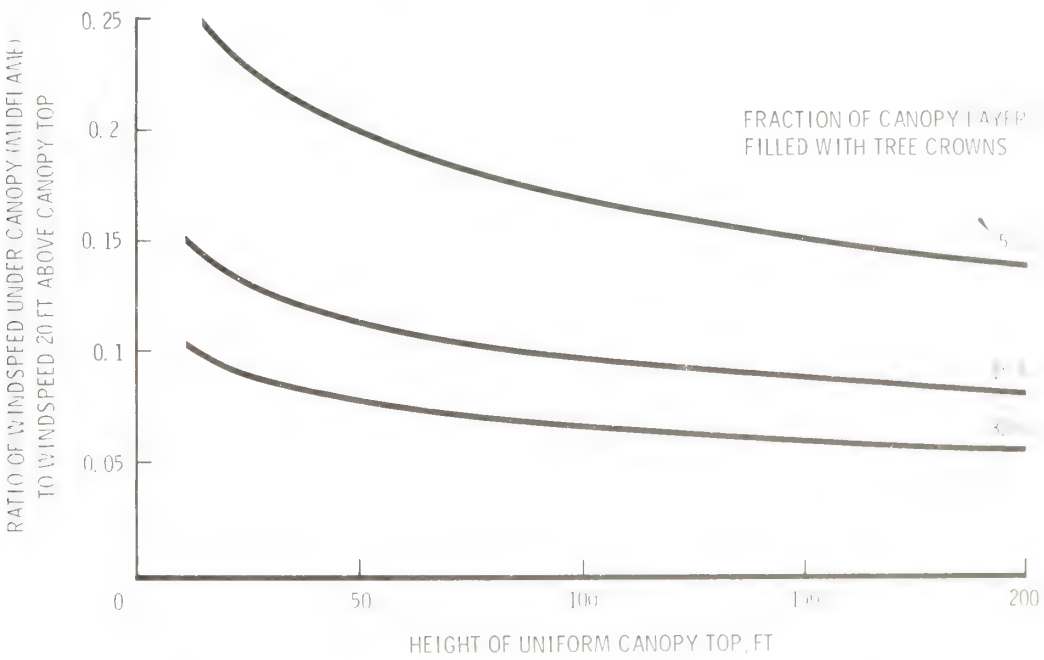
Three "typical" tree heights are used in this table for young stands (40 ft), mature stands (100 ft) and old-growth Pacific Coast stands (180 ft). For the latter, the crown ratios of "mature" stands from table 2 were used.

Since U_c applies (almost) all the way to the ground, it is the "midflame" windspeed. ence the "midflame" windspeed in relation to the windspeed 20 ft over the canopy can found by using equation (4) and choosing the ratio U_c/U_H from table 3 or calculating from equation (20).

The equation for calculating U_c for stands with arbitrary values of f and H is:

$$U_c/U_{20+H} = 0.555 \Big/ \left\{ \sqrt{fH} \ln \left((20 + 0.36H) / 0.13H \right) \right\} \qquad (21)$$

e ratio U_c/U_{20+H} is plotted in figure 3 for the typical and extreme values of f able 2).



canopy top.

COMPARISON WITH MEASUREMENTS

Table 4 compares data reported by Shaw (1977) and Berglund and Barney (1977) with our calculated windspeed ratios U_c/U_H from equation (20) using the values of f from table 2. Table 5 compares calculated values of U_c/U_{20+H} from equation (21) and table 3 with data taken from Fons (1940), Raynor (1971), and Allen (1968). The agreement between model results and measurements is surprisingly good in all cases.

Table 4.--*Windspeed ratio* U_c/U_H

Species	Stand description	Data source	U_c/U_H Calculated	U_c/U_H from published data
Sitka spruce	H = 34.5 ft, S.T., dense	Shaw (1977)	0.167	0.16
Scots pine	H = 50.9 ft, S.T., open	Shaw (1977)	0.259	0.24
Ponderosa pine	H = 70 ft, S.I., open	Shaw (1977)	0.297	0.34
Japanese larch	H = 34.1 ft, S.I., open	Shaw (1977)	0.359	0.36
Black spruce	H = 11.5 ft, S.T., open	Berglund & Barney (1977)	0.619	0.63*

*p. 10, Table 2, ratio of slopes of regression equations relating windspeeds within and above the stand.

Table 5.--*Windspeed ratio* U_c/U_{20+H}

Species	Stand description	Data source	U_c/U_{20+H} Calculated	U_c/U_{20+H} from published data
Ponderosa pine	70 ft, S.I., open	Fons (1940)	0.185	ave. 0.182
Red & white pine	34.5 ft, S.I., dense	Raynor (1971)	0.119	ave. 0.145
Japanese larch	34.1 ft, S.I., open	Allen (1968)	0.180	ave. 0.147

APPLICABILITY OF RESULTS

The numerical results derived in this report are subject to the following limitations. The reader is cautioned to be certain that the specified conditions prevail when using these results.

1. Flat terrain has been assumed throughout. If the terrain has substantial slope or roughness, the windfield will reflect this fact, and substantial deviations from these results may occur.

2. Adequate fetch to establish a uniform friction layer has been assumed. The definition of "adequate" fetch is the subject of current research (Shaw 1977), so numerical limits cannot be stated at this time. But near forest edges, lakeshores, or transitions in surface vegetation cover, the results given here may not be accurate.

3. A "well-behaved" windfield is modeled by the relationships herein. If the windfield is not steady, but fluctuates significantly in speed, direction, or both, the friction layer will be continually in a transient state as it responds to the forces at play. During the periods of such variability the results given here may not be applicable.

4. Any interaction between the fire and the windfield that substantially influences the speed or direction of the wind should invalidate these results. We have dealt here with a windfield whose structure is dominated by the influence of the vegetation cover on the friction layer and any factor that disturbs this condition negates the validity of the results given here.

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KEYWORDS: windspeed in forest canopy, windspeed profile, wind influence on fire.

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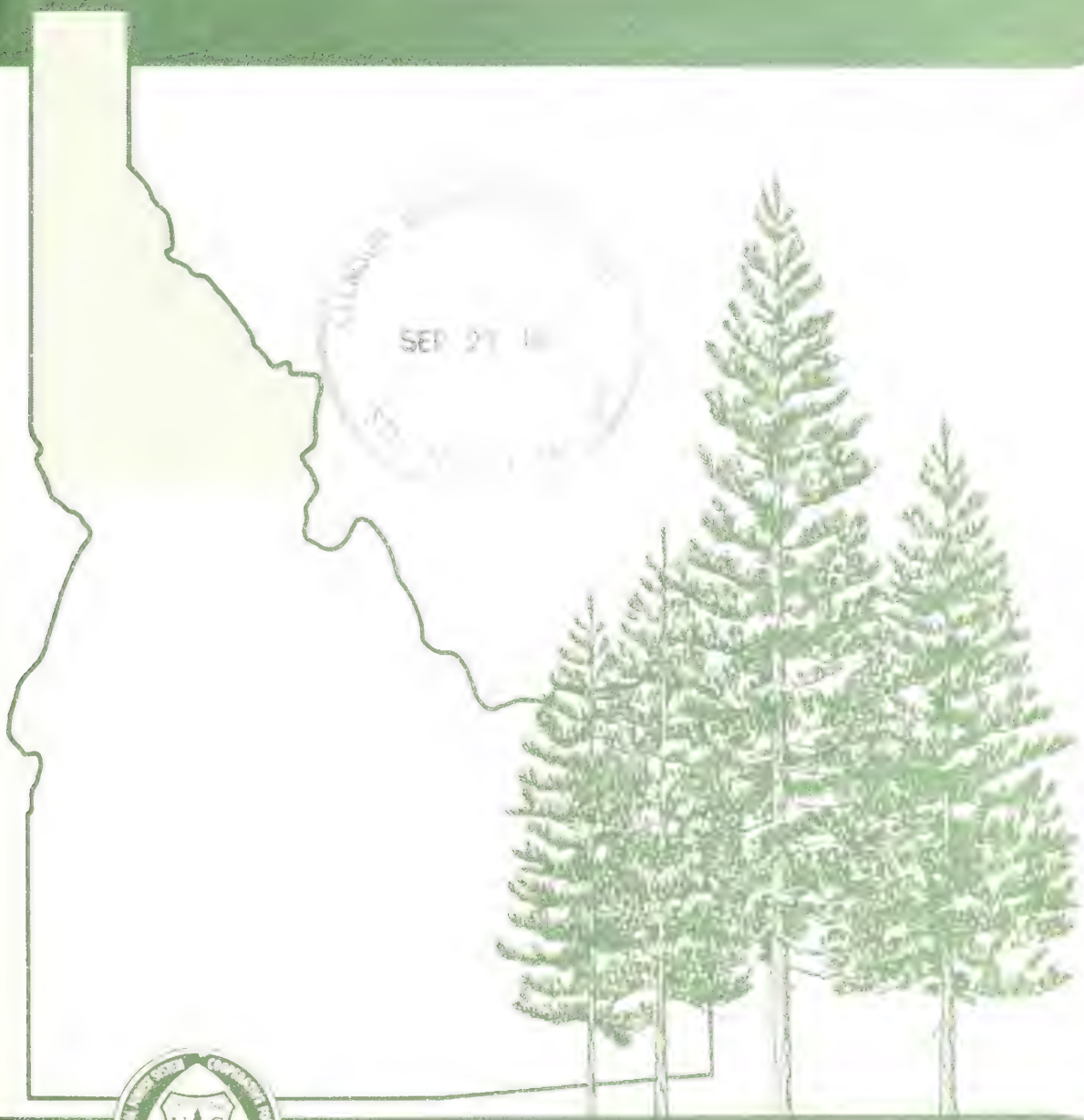
R. J. STEINHOFF



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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE

VARIATION IN EARLY GROWTH OF WESTERN WHITE PINE IN NORTH IDAHO

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RESEARCH SUMMARY

In nursery and field tests representing five different [illegible], little of the variation in height growth or other traits in any one test area was among individual seedlings within family plots. Of the useable genetic variation in those traits, most (60–90 percent) was related to differences among the parent trees within stands. The remaining genetic variation was spread among geographic areas, elevational zones, or stands within these categories. When differences among the latter catagories were significant, usually no pattern in the variation was apparent. Thus, although seedlings within families and family means within stands vary considerably, the lack of differences among stand means, or those for broader geographic areas, and the absence of distinct variation patterns suggests that inland western white pine is fairly uniform. However, seedlings from high-elevation parents (generally 1,375 m or higher) were significantly shorter than those of low- and mid-elevation parents in some low- or mid-elevation tests. Even when elevational effects were not significant very few high elevation families were among the tallest. Growth results to date indicate that only two seed zones are needed in north Idaho--a low zone and a high zone generally separated at 1,375 m. Within the lower zone, trees with good growth potential can be found in nearly all stands.

CONTENTS

	Page
INTRODUCTION	1
PRIOR RESEARCH	1
MATERIALS AND METHODS	2
RESULTS	5
DISCUSSION AND CONCLUSIONS	17
APPLICATIONS	20
PUBLICATIONS CITED	20
APPENDIX	21

INTRODUCTION

Western white pine [illegible] the forests of north Idaho, but the introduction of [illegible] (C. Fisch. ex Rabenh.) and the ensuing losses to the disease has dissuaded land managers from attempting to manage the species. Now, as efforts to produce trees resistant to the disease show some promise, land managers are again [illegible] white pine in their regeneration programs. In the long run, the natural selection process should produce trees with sufficient blister rust tolerance or resistance to allow natural regeneration. For the present and near future, however, planting of resistant seedlings will be needed.

The production and utilization of resistant planting stock involves much more than just securing an adequate level of resistance in a sufficient proportion of the seedlings to be planted. The manager wants the seedlings to survive and grow on the sites he wants to plant and he wants them to grow at a rate which fully utilizes the potential of the site. Attempting to achieve such an ideal match of seedling and site is not a realistic goal at present because of our lack of knowledge of both trees and sites. Also, the costs to approximate such a match would likely exceed the returns from greater yields as the limits of the site are approached. The realistic goal for the present is to attempt to achieve a balance that incorporates our present biological information and approximate costs with expected growth rates and economic returns.

This paper will discuss past and current investigations into variation in growth of western white pine in nursery trials and several experimental plantations. The conclusions of the research will then be translated into guidelines for distributing seed from orchards that have already been established and to evaluate alternative designs for future seed orchards.

PRIOR RESEARCH

During the past 20 years several reports on variation in western white pine have appeared. Squillace and Bingham (1958) opened the series with a report of "localized ecotypic variation" based on germination and early growth of seedlings from quite different sites within a small area. They concluded that seedlings from trees growing on poorer sites were shorter in nursery trials than those from trees growing on better sites. Germination of seeds in a sucrose solution was higher for poorer site trees than for better site trees. In a low-elevation nursery, seedlings from low-elevation trees were taller than those from high-elevation trees, but when transplanted to a high-elevation test site the seedlings from the high-elevation trees grew faster. On the basis of those findings, and other considerations, the applied program to produce blister rust resistant western white pine was subdivided into three elevational zones or breeding units with a seed orchard planned for each. These zones were: (1) low-elevation--areas below 1,000 m; (2) mid-elevation--areas between 1,000 m and 1,250 m; and (3) high-elevation--areas above 1,250 m.

Progeny of many of the same parents used in the above studies were outplanted to two additional sites for long-term evaluation. Rehfeldt and Steinhoff (1970) found that at age 14 average growth at the two sites differed significantly and that the growth of individual progenies differed significantly but the average growth of progenies from different localities did not differ significantly.

In order to obtain materials representative of a broader range of sites, Barnes (1967) systematically collected seed and recorded data from trees in a series of elevational plots along several north Idaho streams. He reported finding significant differences in periodic annual growth rate and branch angle that were related to elevational differences along one transect. Trees in plots from 760 m elevation to 1,220 m grew at essentially the same rate, but those from 1,400 m and above were slower growing. Branch angle changed progressively from low to high plots, with trees in the lower plots having more ascending branches and those in the higher plots having more nearly horizontal branches. Differences among plots were also found in needle length and cone scale length and width, but the variation did not follow a pattern related to elevation.

Some of the seed collected by Barnes was sown in a nursery trial in Michigan. After 4 years of growth, total height of seedlings representing the various elevational and latitudinal collection areas did not differ significantly (Townsend and others 1972). Seasonal growth rates differed, but they did not fit into a pattern related to elevation or latitude. At a very low light level (130 lux) low-elevation seedlings (640 m) were less efficient photosynthetically than higher elevation seedlings (1,065 m and 1,585 m) but at higher light levels (425 and 615 lux) differences were not apparent.

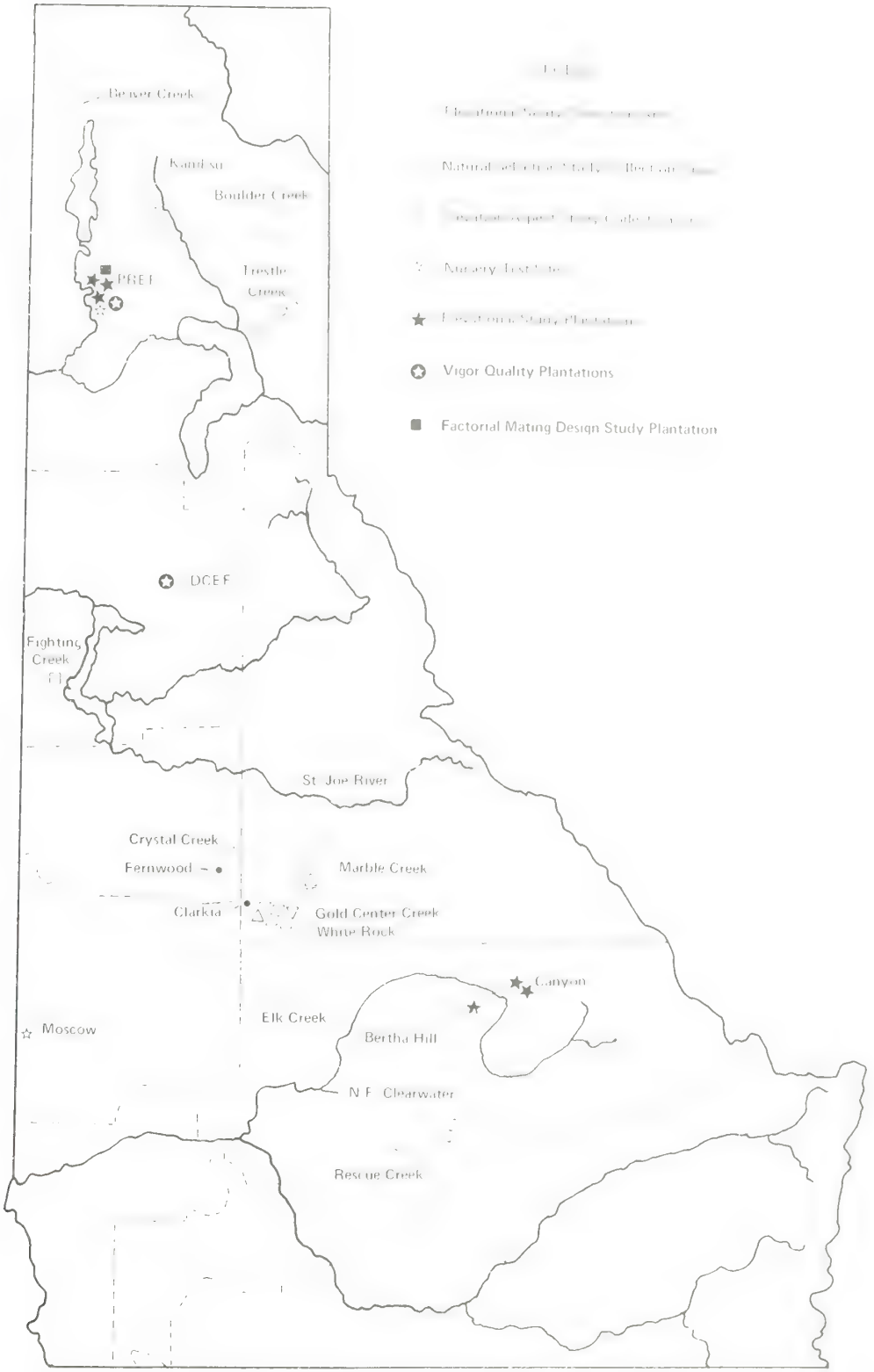
MATERIALS AND METHODS

This report will present and integrate results from five studies, as follows:

1. *Elevational study*.--This study was started to further investigate the effects of elevation (as indicated in Squillace and Bingham 1958) and possibly latitude on seedling growth. Wind-pollinated seed for the test was collected from individual trees in plots (stands) at 120 m to 180 m (mostly 150 m) elevational intervals in several stream drainages in north Idaho. Although the collection locations were often along streams, they were kept out of the stream bottoms where cold air drainage effects are common. Five trees from each of 1 to 3 plots per elevation and drainage were included, for a total of 225 trees in 45 plots (fig. 1). In the Trestle Creek drainage, the plots within an elevational zone were close together (mostly within 0.5 km), but in the other areas the plots were often several kilometers apart. Further details of plot location for the Trestle Creek drainage were presented by Barnes (1967).

A nursery test for early growth and seedling traits was conducted for 3 years at Moscow, Idaho. The seed were sown at a spacing of 5x10 cm in 10-tree row plots in 4 replicates. The growing medium was a mix of forest soil, sand, and peat moss in equal proportions. The beds were watered and fertilized as needed to maintain satisfactory growth. Annual height measurements were taken after growth was completed.

Field plantations have been established at the Priest River Experimental Forest (PREF) and near the North Fork of the Clearwater River on the Canyon Ranger District (Canyon) (fig. 1). In each area, 3 test plantations were established with an elevational separation of 300 m (800 m, 1,100 m, and 1,400 m at PREF and 900 m, 1,200 m, and 1,500 m at Canyon). Aspect of the sites ranges from northeast to northwest. The field tests contain representatives of nearly all the seed collection areas and elevation zones but do not contain representatives of all the plots within elevational zones.


Beaver Creek
Kandesu
Boulder Creek
PSEF
Trestle Creek
DCEF
Fighting Creek
St. Joe River
Crystal Creek
Fernwood
Marble Creek
Clarkia
Gold Center Creek
White Rock
Canyon
Moscow
Elk Creek
Bertha Hill
N.F. Clearwater
Rescue Creek
Vigor Quality Plantations
Factorial Mating Design Study Plantation

An additional plantation (Ida Creek) adjacent to the low PREF site contains representatives of all the families included in the nursery test. The seedlings (3-0 stock) were planted in 1971 at a spacing of 1.8 m in 4-tree row plots replicated 5 times. They were all measured at age 4 (the end of the first field growing season). The Ida Creek plot was measured again at age 6 and age 8 and the other plantations were measured at age 7.

2. *Elevation-aspect study.*--An attempt was made to evaluate the effects of environmental factors related to both elevation and aspect in this test. Study areas were located in two drainages (Marble Creek and Gold Center Creek) near Clarkia, Idaho (fig. 1). They consisted of a series of paired plots at 950 m, 1,175 m, and 1,400 m in each drainage. One member of each elevational pair had a southern exposure and the other a northern exposure. In each plot, four trees were chosen to be seed parents and three to be pollen parents. Pollen from the three trees on a plot was mixed. Each seed tree was pollinated with four pollens, the local pollen mix plus pollens from the low-, mid-, and high-elevation north-aspect Marble Creek plots. For this portion of the study seeds from the four trees on a plot were combined for each pollen type. Results of crosses among individual trees within plots are being reported elsewhere (Rehfeldt, in press).

A nursery test was conducted at Moscow for 3 years. Seed was sown in plots consisting of 2 rows of 18 planting spots. Spacing was 5x10 cm. There were two replicates.

The seedlings have been outplanted to forest test sites but have not yet been measured.

3. *Natural selection study.*--This test was originally designed for studying blister rust resistance, but its potential for studying growth variation within and between stands was soon recognized. Ten stands were located and wind-pollinated seed collected from 50 trees in each. Three of the stands are from the same general areas represented by most of the trees in the vigor-quality study (No. 5 below) and one stand corresponds to one of the elevational study collection areas (fig. 1). Six of the stands fall with the low-elevation zone of the applied program (below 1,000 m) and four within the high zone (above 1,250 m).

The seedlings were started and grown for one season in a greenhouse in 5x5x15 cm tar paper plant bands in a soil, sand, peat moss mix. They were then transplanted, sti in the plant bands, in the PREF nursery site. Eight seedlings of each of the 497 families were planted at random in each of 3 replicates. Spacing was 10x10 cm. The seedlings were given routine nursery care. They were inoculated with spores of the white pine blister rust fungus (*Cronartium ribicola*) at age 3 and measured at age 4, before the disease had any noticeable effect on growth.

Other seedlings from the same families have been outplanted to a field test site but have not been measured yet.

4. *Factorial mating design study.*--This is another test that can serve both blister rust resistance breeding and growth analysis. Three factorial mating designs, one each for the low-, mid-, and high-elevation zones, were established. Four trees were used as pollen parents and approximately 40 trees were used as seed parents in each zon However, the majority of the seedlings in the test plantation represent only 40 familie from each zone (4 pollen parents x 10 seed parents).

The seedlings were grown for 6 years in replicated row plots at the Moscow nursery They were inoculated for studying white pine blister rust resistance. No growth measurments were taken in the nursery.

The survivors from the blister rust testing were outplanted to a low (750 m), nearly flat site at PREF in 1971. A variable number (average 15) of seedlings per

amily were planted as single tree plots at [illegible]
uring the 5-year period from 1953 to 19[illegible]

5. [illegible]. This is the oldest of the studies
uring the early stages of the progra[illegible] to produce
ine (Squillace and Bingham 1954). [illegible]
o investigate the heritability of growth and quality traits.
he seedlings grow in the Crystal Creek drainage near [illegible]
f about 870 m (fig. 1). A few others grow at three additional locations.
our candidates from the White Rock area at an elevation of 1,525 m near Clarkia, Idaho,
ere also included. Squillace and Bingham's (1958) report of "localized ecotypic varia
ion in western white pine" was based on other seedlings of many of these same families.

Seedlings (2-1) for the 1955 outplantings were grown in a nursery in Missoula, Mont.
ll the others were grown in Spokane, Wash. The seedlings were not measured in the
urseries.

Three plantations were installed during the years from 1955 through 1959. Data
rom the 1955, 1956, and 1957 plantings at PREF and Deception Creek Experimental Forest
DCEF) are included in this report. The PREF plantation is located on a moderate (10-
5 percent) north to northwest-facing slope at an elevation of 790 m. The DCEF planta-
ion is on a steep (30-50 percent) north-facing slope at 1,110 m (fig. 1). Seedlings
mostly 2-1 transplants) were planted at a spacing of 2.4 m in 8-tree row plots in three
eplications at each site. Competition from native vegetation has been reduced by weed-
ng and brush cutting at irregular intervals. The trees have been measured several
imes--most recently when all had been in the field for 16 years.

RESULTS

Elevational study.--The most striking feature of the nursery results is the general
ack of patterns in the variation observed (table 1). Although the amount of variation
resent was large, much of it was related to differences among the offspring of a single
ree or among the trees within a stand. This may be seen in the proportion of variance
ttributable to the various sources and the common significance of the "trees within
tands" mean squares (table 2 and Appendix table 15). Because of the magnitude of the
ithin-stand variation, the differences among stands, elevational zones, or geographic
reas were seldom statistically significant.

Seed weight did not differ significantly from one area to another and only within
he Clearwater drainage were there significant differences among elevational zones.
here, seed from the higher elevation trees was lighter than that from the lower trees,
ith a rather consistent gradation between.

Seeds from the Trestle Creek area germinated sooner than those from other areas,
ut there was no pattern to the variation within areas. Whether the germination dif-
erences are inherent or were related to cone collection time or subsequent handling is
nknown. Time of germination was closely related to first-year seedling height and
ome of the effect was still detectable at the end of the third year. All data for
eedlings germinating more than 21 days after the start of germination were excluded
rom these and the following analyses.

Table 1.--[illegible]

Seed collection area	Elevation	Seed weight	Germination time	1st year height	Adjusted 1st year height	2nd year height	2nd year height	3rd year height	Adjusted 3rd year height	Cotyledon No.	Cotyledon length	Bud burst	Bud set	Needle length
	Meters	Mg.	Days[1]											
Clearwater	455	21.5	14	41	41	67	12	195	203	7.7	20			59
	760	19.7	14	39	40	68	13	203	218	7.7	20			57
	915	19.2	13	43	45	75	13	212	215	8.1	20			58
	1065	18.8	14	40	43	68	12	184	194	7.6	20			58
	1220	17.1	12	41	43	68	16	206	216	7.6	19	2.8	8.0	60
	1370	19.0	13	36	42	61	19	182	203	7.5	18			56
	1585	15.6	13	34	41	60	19	195	220	7.8	18			56
	x	18.1	13	40	43	67	15	199	212	7.7	19			58
Trestle	640	18.6	10	45	44	78	13	217	214	7.8	20	3.3	9.3	57
	760	18.4	8	48	45	81	10	227	216	7.9	19	3.3	10.3	61
	915	19.2	6	51	46	87	9	234	214	7.9	20	2.6	9.3	62
	1065	18.7	9	46	44	77	13	225	217	8.1	20	2.8	8.9	59
	1220	18.0	8	48	46	81	9	225	212	8.1	20	3.1	9.7	61
	1400	17.8	9	45	44	76	14	221	219	7.9	20	3.6	10.4	61
	1585	18.8	10	44	43	76	10	211	211	7.9	20	2.2	7.8	61
	x	18.3	9	47	45	80	11	223	215	7.9	20	3.0	9.5	60
St. Joe	915	19.0	9	48	46	80	11	222	215	7.7	20			60
	1065	18.2	10	46	46	76	10	212	209	7.9	20			61
	1220	18.0	12	41	43	70	13	212	221	8.1	19	1.8	7.8	61
	x	18.4	10	45	45	75	12	215	215	7.9	20			61
Yaniksu	915	16.9	16	36	38	62	12	166	173	8.0	18			55
	1065	17.7	12	40	40	71	16	207	199	7.8	20			56
	1220	17.9	13	37	37	63	15	189	194	7.7	19	3.2	8.3	55
	x	17.6	13	38	38	66	15	192	192	7.8	19			55

[1]Days after May 30, 1968.
[illegible]First year height adjusted for seed weight and germination time effects.
[illegible]Does not include lammas growth.
[illegible]Third year height adjusted for first year height differences.
[illegible]Days after April 27, 1970.
[illegible]Days after May 2, 1970.

ource of riation			1st								
			1st year								

When the raw data for the first-year height were analyzed, the mean squares associated with areas were highly significant. This was true for both comparisons, for example, between Clearwater and Trestle where the broadest elevational range was sampled, and among all areas but utilizing only the 915 m, 1,065 m, and 1,220 m elevation zones (those common to all areas). The early germinating Trestle seedlings were taller than the later germinating seedlings from the Clearwater and Kaniksu areas. However, when first-year heights were adjusted for seed weight and germination time the variability related to areas was much reduced. The comparison of all areas using the middle elevational zones showed no significant differences, but the Trestle Creek and Clearwater areas differed at the 5 percent level when all elevation zones were considered. These adjusted means differed by only 2 mm--approximately 4.5 percent of the mean.

Subsequent height measurements taken in the second and third years followed a pattern similar to first-year height. Analyses of the raw data showed significant differences among trees within stands and among areas. There were few or no significant differences among elevations within areas or stands within elevations. When the data were adjusted to take into account first-year height differences, second- and third-year height differences among areas were not significant. In other words, the Trestle Creek seedlings, which germinated early and were tallest at age 1, were still tallest at age 3 but relative to their height at age 1 they had not grown as much as seedlings from the Clearwater and Kaniksu areas.

Whether such adjustments should be made depends on the cause of the germination time difference. If it is the result of genetic differences, no adjustment should be made. If the difference resulted from cone collecting or seed processing timing or techniques, then the adjustments would be appropriate. In the absence of information to indicate genetic differentiation of germination time, I favor use of the adjusted data.

If the range of 120- to 180-m elevational zones is combined across areas to form three broader zones called low, mid, and high (<1,000 m, 1,000-1,250 m, >1,250 m) like the classification in the following studies, then seedlings of the low zone were tallest and those of high zone were shortest. At age 3, heights by zone were: low - 220 mm, mid - 211 mm, high - 207 mm. These means did not differ significantly.

Secondary leaf length (mature third-year leaves) was the only other trait in which differences among areas were significant. Within the Trestle Creek and Clearwater areas, differences between trees within stands were significant but for the other areas they were not. Stand-to-stand differences within an elevational zone were sometimes large but seemed to occur at random. Significant cotyledon differences--number and length--were confined to trees within stands and stands within elevational zones.

Bud burst at the start of the third year did not differ significantly among stands, elevations, or areas (table 3). The highest elevation source from Trestle Creek was the first to break bud but the next to highest source was last. All buds broke within a 2-week period and most within a 5-day period. The newly emerging leaves were rapidly separated and in from 10 to 14 days the tip of the new bud was distinguishable. At that time the seedlings were classified as having set buds even though stem elongation and external bud development continued for nearly a month. No significant differences in bud set time were observed except among trees within stands.

The seedlings were 7 years old and had been in the field plots for 4 years when they were last measured. Overall survival of seedlings of Clearwater origin was about 10 percent less than that of Trestle seedlings with the differences greatest at the Canyon series of test sites. However, survival differences so far do not clearly indicate differences related to area or elevation of origin or their interactions with test site conditions. Average height ranged from 54 cm at the best site, low PREF, to 34 cm at the poorest, high PREF (table 4).

Table 5. [illegible]

Area	Source	d.f.	Mean square	[illegible]	[illegible]	[illegible]
Trestle Creek (610 to 585 m plots)	Replications	[illegible]	65.1	[illegible]	[illegible]	[illegible]
	Elevation	[illegible]	[illegible]	[illegible]	[illegible]	1.2
	Plots within elevations	[illegible]	[illegible]	0.9	[illegible]	
	Trees within plots within elevations	28	12.1	0	[illegible]	8.1
	Experimental error[1]	84	16.8	[illegible]	[illegible]	[illegible]
	Within plot	672	[illegible]	66.1	[illegible]	82.4
220 m plots from Clearwater, St. Joe, Trestle Creek, Kaniksu	Replications	5	14.2	2.1	101.1	[illegible]
	Areas	4	58.7	7.8	101.0	[illegible]
	Trees within areas	10	[illegible]	[illegible]	[illegible]	[illegible]
	Experimental error[1]	42	[illegible]	9.0	20.2	[illegible]
	Within plots	210	4.1	71.8	[illegible]	[illegible]

[1]Includes all interaction terms involving replication.
[2]* and ** indicate significance at the 5 percent and 1 percent level, respectively.

At the individual test sites the results of the analyses of total height are very similar to those from the nursery trial (table 5 presents the results for only the most variable series of sites, i.e., PREF). Most of the variability is related to difference among the families representing individual trees within stands. The variability within plots (i.e., among seedlings of the same family) is also large--nearly equaling that among plots (experimental error). This result indicates that within-family variation is large or microsite differences exert strong influences or that both are important contributors. The variation related to area of seed origin or to elevational zones within areas was very small in comparison and usually not significant.

The Trestle Creek seedlings were taller than those from the Clearwater at the low and high sites at both PREF and Canyon, but the Clearwater seedlings were as tall or taller at the mid-elevation sites. No pattern could be seen in the variation in height among seedlings related to the various elevational zones within areas. Neither was there any correspondence between elevational zones in the different areas. For example, seedlings from the highest Clearwater collections grew well at most test sites but those from the highest Trestle Creek collection grew poorly. As a group, the seedlings from

Table 4.--*Height of seedlings at age 7 in the elevational study field tests*

Seed collection		Test region and site								
		Canyon[1]				PREF[2]				Overall
Area	Elevation	Low	Mid	High	$\bar{x}$	Low	Mid	High	$\bar{x}$	$\bar{x}$
	Meters	*Centimeters*								
Clearwater	760	37	40	38	38	55	39	30	43	41
	915	42	40	37	40	53	38	34	42	41
	1065	37	41	33	37	51	35	32	40	38
	1220	41	41	35	39	50	36	33	40	40
	1370	40	43	35	40	53	34	32	41	41
	1585	44	43	38	42	54	36	34	43	42
	$\bar{x}$	40	42	36	39	53	37	33	41	40
Trestle	760	42	42	36	40	53	37	35	42	41
	915	40	42	42	41	53	35	34	41	41
	1065	45	41	38	41	57	36	36	44	43
	1220	39	41	35	39	55	39	35	44	42
	1400	42	40	37	40	56	35	34	43	41
	1585	39	39	37	38	54	37	34	42	40
	$\bar{x}$	41	41	38	40	55	37	35	42	41
Overall	$\bar{x}$	41	41	37	40	54	37	34	42	41

[1]Canyon Ranger District: low = 900 m, mid = 1,200 m, high = 1,500 m.
[2]Priest River Experimental Forest: low = 800 m, mid = 1,100 m, high = 1,400 m.

Table 5.--*Analyses of variance and percent of total variation for height of 7-year-old seedlings in the elevational study sites at PREF*

Source	d.f.	Low site		Mid site		High site	
		Mean square	% of total variation	Mean square	% of total variation	Mean square	% of total variation
Replicates	4	134	0.0	114	0.0	269	0.4
Area	1	1,013*[1]	0.8	5	0.0	793*	1.0
Elevation within Area	10	255	0.0	155	0.4	68	0.0
Rep * Area & Elev (Error 1)	44	240	2.4	131	6.0	192	6.4
Trees within Elev & Area	47	350**	6.6	140**	7.1	220**	8.2
Rep * Tree (Error 2)	170	177	5.3	79	5.2	95	2.4
Within Plot	565	149	84.9	70	81.3	88	81.6

[1]* and ** indicate significance at the 5 percent and 1 percent levels, respectively.

the 760 m Clearwater collection grew poorly at the low [illegible] but well at the high site. In contrast, it [illegible] well at the [illegible] elevation sites but poorly at the high site. However, the [illegible] small--only 2 or 3 cm (5 percent) above or below the site mean [illegible], appear more accidental than the result of specific tree-site interactions.

When the overall variability across sites within test regions [illegible] the variation associated with trees within elevational zones was still predominant over that for elevational zones or areas. The site * tree interaction [illegible] at PREF. When the tree mean squares were tested against this interaction term rather than the error mean squares, the tree effects were significant at only the 5 to 10 percent level.

The average height of the seedlings over the three sites at PREF was essentially the same as that for the Canyon sites but the range at PREF was much greater. Neither group of sites shows a typical spread of conditions for the area. At PREF, growth and survival at the mid-elevation site has been reduced due to poor site quality and residual competition resulting from site preparation problems. At Canyon, the low site trees suffered from similar site preparation problems.

Table 6.--*Analysis of variance of [illegible] seedlings of the [illegible]*

Source	d.f.	Canyon		PREF	
		Mean square	% of total variation	Mean square	% of total variation
Test sites[1]	2	5,829	1.9	106,0[illegible]	[illegible]
Replicates within sites	12	302	1.1	172	[illegible]
Area	1	127	0	[illegible]	[illegible]
Site * Area	2	177	0	[illegible]	0.4
Elevation within Area	10	290	0.2	278	[illegible]
Site * Elevation	20	168	0	101	0
Rep * Area & Elev (Error 1	132	149	2.8	[illegible]	2.0
Trees within Elevations and Areas	48	21[illegible]	1.[illegible]	[illegible]	0.7
Site * Tree	94	142	[illegible].1	[illegible]	2.8
Rep * Tree (Error 2)	500	111	[illegible]	[illegible]	1.5
Within Plot		110	87.0	109	[illegible]

[1]Low, mid, and high elevation.

** and ** indicate significance at the [illegible] percent and [illegible] respectively.

[illegible] At Canyon d.f. [illegible] 1,001, at PREF [illegible] 2,001.

In the Ida Creek plantation adjacent to the low PREF plot, where all the families included in the nursery test were planted, area differences were significant at age 4 but became less important and nonsignificant by age 6. Actually, the difference betwe area means remained nearly constant (2 cm between Clearwater and Trestle Creek), but a a percentage of total height that difference dropped from 7 percent at age 4 to only 2 percent by age 8.

When all the families were grouped as to low, mid, or high origin, as with the nursery data, then height at age 8 decreased from low to high elevation (101, 100, and 98 cm, respectively). These differences were not significant and that result is contrary to the findings in the adjacent low plot where the high-elevation seedlings were slightly taller than the low- and mid-elevation seedlings.

Elevation-aspect study.--Height at the end of the third year in the nursery (table 7) did not differ significantly among drainages, elevations, aspects, or pollen types. Rehfeldt (in press) also found that at age 6 differences among drainages, elevations, or aspects were not significant when tested by individual control-pollinated families within plots. Seedlings from south aspect plots in this study were generally taller than those from north aspect plots in the same drainage and at the same elevatio This was also the result for the Gold Center Creek drainage in Rehfeldt's study, but seedlings from north and south aspect Marble Creek plots were essentially equal in hei

Table 7.--*Third year height of seedlings in the elevation-aspect study*

Seed parent location			Pollen source						
			Marble Creek north aspect						
Drainage	Elevation zone[1]	Aspect	Low	Mid	High	Local	$\bar{x}$	$\bar{x}$	$\bar{x}$
			Height (millimeters)						
Gold Center Creek	Low	North	71	71	75	64	70	75	
		South	67	84	80	87	79		
	Mid	North	75	73	83	--	80	83	78
		South	76	69	87	108	85		
	High	North	73	85	65	72	74	76	
		South	71	73	84	84	78		
Marble Creek	Low	North	--	--	88	85	86	85	
		South	84	87	77	87	84		
	Mid	North	74	--	75	79	76	78	81
		South	84	78	74	84	80		
	High	North	--	--	--	75	75	78	
		South	64	84	87	84	80		
		$\bar{x}$	74	78	80	83			

	$\bar{x}$		$\bar{x}$
L	79	N	76
M	80	S	81
H	78		

[1]Low = 950 m, mid = 1,175 m, high = 1,400 m.

Overall, the seedlings produced by local [illegible] with pollen from the north aspect plots but the [illegible]. On the south aspect plots, local pollens produced seedlings significantly taller than those produced by the north aspect pollens. On the north aspect plots, pollen from one of the other north plots usually produced taller seedlings than did local pollen.

Among the north aspect Marble Creek plots, seedlings from the low plot were tallest but pollen from the plot produced the shortest seedlings when used on trees in other plots. For the high plot, the results were the opposite (seedlings from the plot trees were short but pollen from the plot produced tall seedlings when used elsewhere). Such reversals were probably the result of large amounts of within-plot variability coupled with the small numbers of trees chosen to be pollen or seed parents in any one plot rather than resulting from plot interactions.

[illegible].--In this study only growth during the fourth growing season was measured and analyzed (tables 8 and 9). The mean growth of the [illegible] stands was significantly less than that of the 6 low elevation stands (10.8 cm vs. 11.8 cm). However, the best high elevation stands grew more than the poorest low-elevation stand. Among the 6 low elevation stands, the 4 fastest growing ones [illegible] significantly from the slowest growing one.

Even though the differences between elevational groups and among stands were significant, the bulk of the genetic variation (61 percent) was associated with differences among trees within stands. Of the remaining genetic variation, 28 percent was due to elevational differences and 11 percent to differences between stands within elevational zones. Overall, 62 percent of the variation was related to variation among seedlings from the same tree, 2 percent to block interactions, and 36 percent to genetic variation.

Table 8.--[illegible]

Stand	Elevational zone[1]	Growth	Range of family means	Number of families
		- - - - [illegible] - - - -		
Beaver Creek pole	Low	12.4 a	8.8-15.4	[illegible]
Crystal Creek	Low	12.2 a	[illegible]	[illegible]
Beaver Creek mature	Low	12.2 a	8.3-16.1	[illegible]
Montford Creek	Low	11.9 ab	[illegible]	[illegible]
Fighting Creek	Low	11.7 abc	9.3-16.1	[illegible]
Rescue Creek	High	11.4 bcd	8.2-14.8	[illegible]
Bertha Hill	High	11.1 cd	[illegible]	[illegible]
Elk Creek	Low	10.9 cd	8.2-13.7	[illegible]
Boulder Creek	High	10.8 cd	8.0-14.9	[illegible]
White Rock	High	10.6 d	7.5-13.0	[illegible]

[1]Low = below 1,000 m, high = above 1,250 m.
[2]Means not having a letter in common differ at the [illegible].

Table 9.--*Analysis of fourth year height growth of seedlings in the natural selection study*

Source	d.f.	S.S.	M.S.	F	Variance component	Percentage of total variance
Block	2	622	311		0.09	0.005
Stand	9	3260	362	7.9*[1]	.35	.02
Elevation	1	1728	1722	9.0*	.24	.014
Stand (Elev)	8	1538	192	4.2**	.11	.006
Block*Stand	18	825	46		.11	.006
Tree (Stand)	487	15468	32	2.1**	.95	.06
Block* Tree(Stand)	969	14727	15		.00	.00
Within family	7054	108648	15		15.40	.91

[1] * and ** indicate significance at the 5 percent or 1 percent level, respectively.

Factorial mating design study.--Seedlings from crosses among mid-elevation (1,000-1,250 m) trees grew the most between ages 8 and 11 and were tallest at age 12 (table 10). As a group they differed significantly from both the low- and high-elevation families in growth and from the high-elevation families in height (table 11). The low- and high-elevation means did not differ significantly.

Approximately 90 percent of the total variability was associated with differences among seedlings within families and environmental effects. Of the remainder, 67 percent of the variability in growth and 80 percent of the variability in height was associated with differences among families within elevation zones and only 33 percent or 20 percent associated with differences among elevation zones.

Although the mid-elevation group was tallest as a whole, the tallest family was from the low-elevation group. The low group also had a higher ratio of better families than either the mid- or high-elevation groups (1/5 vs. 1/8 and 1/36 families in the top 10 percent, respectively).

Table 10.--*Growth and height of seedlings in the factorial mating design study*

Elevational zone[1]	Growth between ages 9 and 11	Height age 12
	Centimeters	
Low	44	101
Mid	48	106
High	45	99

[1] Low = below 1,000 m, mid = 1,000 to 1,250 m, high = above 1,250 m.

Table 11.—[illegible]

Source	d.f.	M.S.	[illegible]	[illegible] of total
Growth between ages 9 and 11				
Elevational zone	2	[illegible]	1.3	1.4
Family (Elev.)	95	432**	8.6	2.7
Within Family	1382	301	301.4	95.9
Height age 12				
Elevational zone	2	7710*	[illegible]	1.9
Family (Elev.)	95	1621**	[illegible]	7.6
Within Family	1382	716	[illegible]	[illegible]

[1]* and ** indicate significance at the 5 percent and 1 percent level, respectively.

Vigor-quality study.--The main reasons for including this study are that the tr[illegible] are old enough to have reached a stable growth pattern and to show how the results have changed over the years. The mean height of the low elevation families has been con[illegible]tently greater than that of the high elevation families (table 12). Significant differences during the early years, ages 4 to 8 (table 13), probably resulted from the combination of a carryover of nursery differences (Squillace and Bingham 1958) and limited competition on the recently cleared sites. By age 8 competition from the n[illegible] vegetation was increasing and until age 12 or 14 when most trees were taller than t[illegible] brush all families probably grew less than their potential. That competition proba[illegible] was also responsible for keeping the differences between elevational zone relat[illegible] constant while between-family and within-plot variation increased [illegible]. After the trees overtopped the brush, their growth potential could be realized more fully. Then height and growth rate differences between the low and high zone[illegible] significant.

During the last 3 years, differences between the low and high families continued to increase but at a slower rate. At the same time, differences among families within elevational zones became larger, resulting in a decrease in the significance of the elevational difference. The elevational difference exhibited in this study is probably larger than would be found if more stands, and trees, had been sampled. The results from the natural selection study reported earlier indicate that trees of the high elevation stand (White Rock) used in this study produce the slowest growing seedlings of the high elevation stands sampled. Also, most of the low elevation trees are from a stand (Crystal Creek) that produces some of the fastest growing seedlings. Thus, by chance, these results and those of Squillace and Bingham (1958) contrast the poorest high trees we have studied with some of the best low trees. Even then, the best high family has been taller than several of the low families.

Height growth of the young trees at the two sites was essentially equal until age 10 and did not differ significantly until age 16. Interactions between sites and elevational origin of the seedlings were essentially nonexistent even after the height difference between the sites became highly significant.

Table 12.--*Height and growth of young trees in the vigor-quality study at various ages*

Height at age		DCEF		PREF		Combined	
		Low elevation families[1]	High elevation families[2]	Low elevation families	High elevation families	Low elevation families	High elevation families
		Meters					
4	$\bar{x}$	0.11	0.09	0.11	0.09	0.11	0.09
	Range	0.08-0.15	0.09-0.10	0.08-0.13	0.05-0.13		
8	$\bar{x}$	0.61	0.56	0.62	0.51	0.62	0.54
	Range	0.51-0.72	0.46-0.62	0.41-0.71	0.31-0.58		
10	$\bar{x}$	0.97	0.91	0.94	0.85	0.95	0.88
	Range	0.76-0.12	0.76-1.00	0.67-1.10	0.58-1.00		
12	$\bar{x}$	1.6	1.5	1.8	1.6	1.7	1.6
	Range	1.3-1.9	1.3-1.7	1.3-1.9	1.1-1.8		
14	$\bar{x}$	2.5	2.2	2.9	2.5	2.7	2.4
	Range	2.0-3.0	2.0-2.5	2.2-3.1	2.1-2.7		
16	$\bar{x}$	3.5	3.0	4.1	3.6	3.8	3.3
	Range	3.0-4.1	2.8-3.3	3.4-4.3	2.8-4.1		
19	$\bar{x}$	5.4	4.7	6.3	5.8	5.9	5.2
	Range	4.6-6.1	4.0-5.1	5.2-6.8	4.7-6.5		
Growth between ages		*Meters/year*					
12 & 16	$\bar{x}$	0.47	0.38	0.58	0.50	0.52	0.44
	Range	0.38-0.53	0.32-0.42	0.51-0.60	0.42-0.57		
16 & 19	$\bar{x}$	0.63	0.56	0.75	0.75	0.69	0.64
	Range	0.57-0.69	0.46-0.61	0.60-0.85	0.68-0.79		

[1]Average elevation 925 m.
[2]Average elevation 1,525 m.

Table 15. [illegible]

Trait measured	Test site and source of variation				
	DCEF	PREF	[illegible]	[illegible]	
	Elevation zone[1]	Elevation zone[1]	Test site[2]	Elevation zone	Elevation
Height at age:					
4	6.56*[4]	4.77*	1	.31*	1
8	1.93	4.84*	<1	7.64*	.1
10	<1	1.48	<1	2.06	.11
12	1.96	2.59	1.25	4.46	
14	4.12	6.16*	7.14	3.47	
16	8.98**	7.03*	12.5*	12.4**	
19	8.15	4.98	31.0**	10.2**	1
Growth between ages:					
12 & 16	17.6**	14.1**	35.4**	30.0**	
16 & 19	5.04*	<1	109.7**	4.04	<1

[1]"F" value resulting from the comparison $\frac{\text{Elevation zone mean square}}{\text{Trees within elevation zone mean square}}$

[2]"F" value resulting from the comparison $\frac{\text{Test site mean square}}{\text{Rep within site mean square}}$

[3]"F" value resulting from the comparison $\frac{\text{Site X elevation mean square}}{\text{Rep within site X elevation mean square}}$

[4]* and ** indicate significance at the 5 percent and 1 percent level, respectively.

Although the differences among families within elevational zones were large (the range between tallest and shortest varied from 10 percent to 35 percent of the mean at different ages), the differences were seldom significant because of the small numbers of families tested and large amounts of within-family variability. The variance attributable to family-by-site interactions was small and nonsignificant except at age 8. The question of family-by-site interactions is even more confusing if one also includes year of planting. A few families were planted in each of 2 or 3 years. For some of these families the seedlings planted in 1955 may have grown faster at PREF than DCEF but those planted in 1957 grew faster at DCEF or vice versa.

DISCUSSION AND CONCLUSIONS

To date all of our studies with western white pine indicate that the majority of the variation which might be utilized in a tree improvement program is related to the differences among individual trees within stands rather than to differences among stands, elevational zones, or geographic areas. When stand or area differences were significant, there did not appear to be a pattern to the variation. In most of the tests, seedlings from high elevation parent trees (generally 1,575 m or above) grew slower than those from lower elevation parents. The differences were significant in only about half of the tests and the average growth of seedlings from some high stands was good. However,

if one were selecting only those families that were in the top 10 percent group for height in any one test, very few of the high-elevation families would be selected (table 14). Among the lower elevation zones there again appeared to be no pattern to the variation.

The general finding from these studies that seedlings from high elevation trees a slower growing than those from lower trees agrees with the results reported earlier by Squillace and Bingham (1958). However, these data do not agree with their findings th high-elevation families grew slower than low-elevation families in a low nursery and l plots but faster at a high plot. In the vigor-quality study, low-elevation families w significantly taller than high-elevation families at both low- and mid-test sites. Wh the differences in sites were not as great as in Squillace and Bingham's study, the si means did differ significantly and there was no indication of the high-elevation famil growing faster at the higher site. In fact, the difference between low- and high-elev tion families was greater at the higher site even though total height was less. Simi- larly, as mentioned above, in the elevational study high-elevation families were as ta or slightly taller than low- or mid-elevation families at the low sites but slightly shorter at the high sites. Thus, up to this time the results of the present studies suggest that groups of families representing various elevational zones perform nearly the same whether tested at low-, mid-, or high-elevation sites.

Table 14.--[illegible] trees in top 10 percent group in various studies

Study	Seed collection elevational zone		
	Low	Mid	High
Elevational			
Nursery	1/7	1/11	1/39
Ida Creek	1/7	1/10	1/35
PRIL			
Low site	1/20	1/7	1/10
Mid site	1/4	0	1/20
High site	1/20	1/7	1/10
$\bar{x}$	1/9	1/10	1/12
Canyon			
Low site	0	1/10	1/5
Mid site	1/20	1/20	1/5
High site	1/5	0	1/6
$\bar{x}$	1/12	1/20	1/6
Natural selection	1/7	1/17	1/33
Factorial mating design	1/5	1/8	1/36
Overall	1/7	1/10	1/26

Chance selection and sample size appear to contribute to the conflicting results of the various studies. The vigor-quality study contrasted low- and high-elevation stands, but it sampled only four trees in the high one. Subsequent results from the natural selection study where 50 trees were sampled per stand confirm the differences among the low and high stands represented in the vigor-quality study, but also show that other choices of single low and high stands could lead to the conclusion that low and high stands do not differ.

On the other hand, the elevational study sampled a much broader range of stands but again with few trees per stand. Consequently, the lack of differences among low and high stands may be too conservative. For example, two 5-tree collections were obtained from a stand at Bertha Hill at 1,585 m in the Clearwater area for the elevational study. Seedlings from one of these collections were the tallest of the Clearwater collections but those from the other were about average. The mean height of the two was only slightly less than that for the best elevational zone. However, the results from the 50-tree collection made for the natural selection study indicate that although seedlings from this stand are among the fastest growing of the high-elevation stands they are slower growing than those of five of the six low-elevation stands. Among the low-elevation stands in the natural selection study, even a 50-tree sample indicated only that seedlings of the poorest stand differed significantly from the best ones.

The results of this group of studies also differ from those found in other western conifers. Callaham and Liddicoet (1961) found that mid-elevation ponderosa pine families were tallest at low-, mid-, and high-elevation sites during the first 20 years after outplanting. However, although the high-elevation trees were doing very poorly at the low- and mid-elevation sites at age 20, at the high site they were taller than the low trees and nearly as tall as the mid trees. This pattern continued through age 29 (Conkle 1973). Conkle also found that the variance component related to elevation zones was much larger than that for families within zones at the low and mid sites but not at the high site. In our studies the family component was always much larger.

In working with Douglas-fir, Rehfeldt (1974) found that differences between low, or warm, habitat type trees and high, or cool, habitat type trees could be detected with seedlings from as few as 7 trees per stand. He also found growth differences between stands on the east and west sides of the mountain ranges along the border between Idaho and Montana.

In summary, the results from this series of tests indicate that, at least within the north Idaho portion of its interior range, western white pine has a different variation pattern than that of most other conifers that have been intensively studied. Western white pine is highly variable, but most of the variation is related to differences among the offspring of a single tree or among the trees in a stand. Although differences among stands, elevation zones, or geographic areas were sometimes significant, the proportion of the variance attributable to these sources was usually smaller than that for trees within stands.

All of the seedlings involved in the studies reported here were started under protected and irrigated nursery conditions. They escaped the variety of environmental conditions that might lead to ecotypic differentiation during the critical germination and early establishment growth phases often found when reproduction occurs naturally. Squillace and Bingham's (1958) germination test results may indicate such a differentiation, but the results reported here [illegible].

APPLICATIONS

The results to date indicate that only two seed zones are necessary for western white pine in north Idaho, and probably for the adjacent white pine areas in northeastern Washington and northwestern Montana as well. The main, or low, zone would include all the area below 1,375 m, with the exception of the most severe sites where the upper boundary might be lowered to 1,250 m. The second, or high, zone would include all the area above 1,375 m and a limited area related to severe sites between 1,250 m and 1,375 m.

Two seed orchards, with selections related to the above seed zones, should be sufficient for the next phase of the blister rust resistance breeding program. Siblings, or vegetative propagules, of seedlings intended for either orchard should be tested at several sites to facilitate selection of those individuals or families that are both broadly adapted and fast growing.

Seed from the present low- and mid-elevation orchards can be combined and used on low- and mid-elevation sites throughout north Idaho. It can probably be used at elevations up to 1,375 m on most sites. Seed from the high orchard should be used for sites above 1,375 m. This is a conservative approach, as our results so far show little or no difference in survival or growth among seedlings of low-, mid-, or high-elevation origin at the high sites. However, long-term effects have shown up in other species.

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APPENDIX

Table 15.--*Mean squares from the analyses of variance for several seedling traits in the elevation study nursery, test*

Source of variation	d.f.	Traits										
		Seed weight	Germination time	1st year height	Adjusted 1st year height[1]	2nd year height[2]	2nd year lammas	3rd year height	Adjusted 3rd year height[3]	Needle length	Cotyledon No.	Cotyledon length
Trestle Creek vs. Clearwater--All Elevation Zones from 455 m to 1,585 m												
Replications[4]	3	0	393	619	95	1,685	515	17,780	6,817	893	0.0	8.9
Areas	1	28	3,561**[7]	7,913**	580*	22,738**	2,577**	86,262**	1,651	749*	5.2**	52.6*
Elevation zones within areas	13	818	103	325	69	881	235	3,539	1,649	119	0.5	9.3*
Stands within elev. & areas	18	157	80	182	90	536	138*	3,110*	1,599**	86	0.3	4.3
Trees within stands, elev., & areas	130	3,075	50**	141**	60**	343**	58**	1,755**	736*	71**	0.4**	4.1**
Experimental error[5]	471		7	18	18	63	38	707	577	43	0.1	1.7
Within plot[6]			12	52	6	19	6	143	139	10	0.1	0.9
Clearwater, St. Joe, Trestle, and Kaniksu but only 915 m, 1,065 m, and 1,220 m Elevation Zones												
Replications[4]	3		184	284	59	1,046	529	6,927	2,755	798	0.2	15.9
Areas	3	17	685**	2,003**	284	4,923*	601	20,599	170	849*	0.9	8.3
Elevation zones within areas	8	25	66	262	74	867	166	6,180	3,907	126	0.8	6.2
Stands within elev. & areas	11	31	23	144	118	427	83	2,995	1,502*	133**	0.7*	9.3*
Trees within stands, elev., & areas	92	28	55**	155**	65**	341**	46*	1,868**	722**	47	0.4**	4.6**
Experimental error[5]	334		10	19	14	65	34	640	471	39	0.1	1.6
Within plot[6]			2	7	6	19	6	143	139	10	0.1	0.9

[1]First-year height adjusted for seed weight and germination time effects.
[2]Does not include lammas growth in second year.
[3]Third-year height adjusted for first-year height differences.
[4]Only two replicates were used for analyses of cotyledon number and length, so degrees of freedom for replicates and error were reduced accordingly.
[5]Includes all interaction terms involving replication.
[6]Pooled estimate from 30 to 50 plots with 5 to 10 seedlings per plot.
[7]* and ** indicate significance at the 5 percent or 1 percent level, respectively.

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In several nursery and field tests most of the useable variation among western white pine seedlings or saplings was related to differences among the parent trees within stands. When differences among geographic areas, elevational zones, or stands within those categories were significant usually no pattern to the variation was apparent. However, seedlings from high elevation parents (generally 1,375 m or higher) were often shorter than those from lower elevations.

KEYWORDS: geographic variation, elevational variation, Pinus monticola, seed zones

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LOCAL CLIMATIC AND HYDROLOGIC CONSEQUENCES OF CREATING OPENINGS IN CLIMAX TIMBER OF NORTH IDAHO

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RESEARCH SUMMARY

Climatic and hydrologic responses of small openings in [illegible] north and south aspects in northern Idaho were studied. Incoming surface wind, maximum snow deposition, seasonal precipitation, and seasonal percolation--were related to the distance downwind from the west edge of the forested [illegible]. Until [illegible] an exponential increase in each parameter generally occurred as the distance increased. On the south aspect, the same response was observed with surface wind. However, maximum snow deposition, seasonal precipitation, and seasonal percolation increased for a short distance of 1.0 to 2.0 tree heights and then diminished rapidly. Other attributes such as drip, snow interception, snowmelt, and rates of disappearance were evaluated with supportive data.

CONTENTS

	Page
INTRODUCTION	1
EARLIER INFORMATION	1
EXPERIMENTAL SITE	1
STATION LOCATION	2
MEASUREMENT TECHNIQUES	4
DATA COMPILATION	5
PARAMETRIC MODELING	6
EFFECTS OF TOPOGRAPHY AND FOREST CLEARING ON LOCAL CLIMATE	7
Surface Wind	7
Maximum Snow Deposition	8
Seasonal Precipitation	12
SEASONAL, MONTHLY, HIGHEST DAILY AND MEAN DAILY PERCOLATION	15
Seasonal Percolation	15
Monthly Percolation	16
Highest Daily Percolation	18
Mean Daily Percolation	19
Snow Disappearance	21
SNOW DEPTH, SNOW DENSITY AND BIG GAME MOBILITY	22
MANAGEMENT CONSIDERATIONS	24
PUBLICATIONS CITED	25
APPENDIX A	27

INTRODUCTION

Practicing hydrologists, foresters, and [illegible] information about the climatic-hydrologic consequences of creating openings in old imax timber. New information was gained recently from a study conducted in the Priest ver Experimental Forest, an area which typifies much of the sloping forested land of rtheastern Washington, northern Idaho, and western Montana.

The specific objectives of the study were to detect changes in surface wind, precipitation amount, snow deposition and ablation, snow depth and density, and percolation associated with a variety of clearings situated on north and south aspects. The vestigation was conducted from November through May over 5 study years.

EARLIER INFORMATION

Little wintertime work has been done in northern Idaho that has dealt specifically th the local climate and hydrology of different sizes of forest openings. Packer 962, 1971) summarized the results of a comprehensive snow course study conducted in e Priest River Experimental Forest, in which the effect of very small openings was udied. Larger openings, characterizing the usual timber sale, were not available at e time Packer reported and so were not studied. In recent years, larger openings ve become available through a series of timber sales. Cline and others (1977) intenvely instrumented two of these openings to determine snow deposition, snowmelt, perlation rates, soil water content, and potential water yield. This effort provided nsiderable basic data, part of which have been incorporated into this report.

EXPERIMENTAL SITE

The Priest River Experimental Forest is a 6,378-acre (2,577-ha) tract in the Idaho nhandle National Forests north of Priest River, Idaho. Mountainous terrain, with evations ranging from 2,200 to 5,900 feet (671 to 1,798 m), makes up 85 percent of e Experimental Forest. The specific study area overlapped onto both slopes of an st-west oriented ridge between an elevation of 4,000 and 4,600 feet (1,200 and 400 m). The south (180°) slope includes the Douglas-fir/ninebark habitat type; the en overstory consists of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] anco), western white pine (*Pinus monticola* Dougl.), western larch (*Larix occidentalis* t.), and grand fir (*Abies grandis* [Dougl.] Forbes) and the understory contains a xture of shrubs dominated by ninebark (*Physocarpus malvaceus* [Green] Kuntze). The rth (335°) slope is classified as western hemlock/*Pachistima* habitat type (Daubenmire d Daubenmire 1968). The dense overstory was mainly western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western redcedar (*Thuja plicata* Donn.), and western white pine, d the understory contains scattered pachistima shrub (*Pachistima myrsinites*), and w, herbaceous plants.

Soils in the higher elevations of the Experimental Forest are underlain by Precambrian metamorphic rock. The soils, which are derived from glacial till and are pped by a thick layer of volcanic ash, are predominantly silt loam.

The climate is influenced by the Pacific Ocean, hence the winters are cool and t. Summers are dry. Storms and accompanying winds generally move in from the southst, and, to a lesser degree, from the west and south. Most of the annual precipitaon, about 40 inches (102 cm), falls from November through May in form of snow and n. Precipitation for the years 1969-73 was average to above average. The last of e 5 study years, 1973, had the lowest total, 28 inches (72 cm), recorded since 1940.

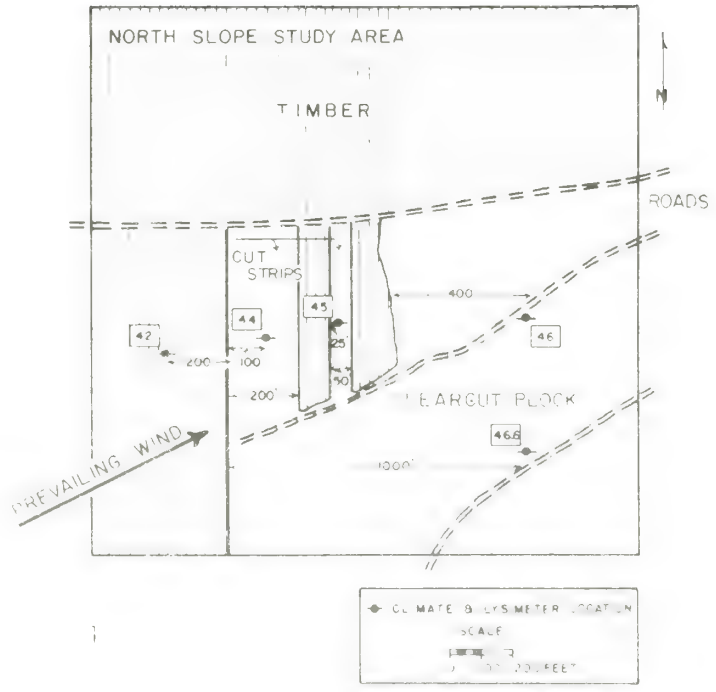
STATION LOCATION

On both the north and south aspects, instrumented stations were located in openings that were clearcut logged in 1968 and 1969. One exception, station N39(0), was positioned in an isolated clearing carved out of the old stand in the 1930's. Stations N45(0) and N44(0) (north) and stations S49(0) and S50(0) (south) were established at the midpoint of individual stripcuts with long axis oriented north-south. Stations N46(0) and N46.6(0) (north) and stations S52(0) and S52.2(0) (south) were positioned in a clearcut block at different distances from the west edge of the forest; the north clearcut block was 65 acres (26 ha), the south, 25 acres (10 ha). The forest or "control" locations are represented by stations N40(T) and N42(T) (north) and S47(T) and S47.7(T) (south).

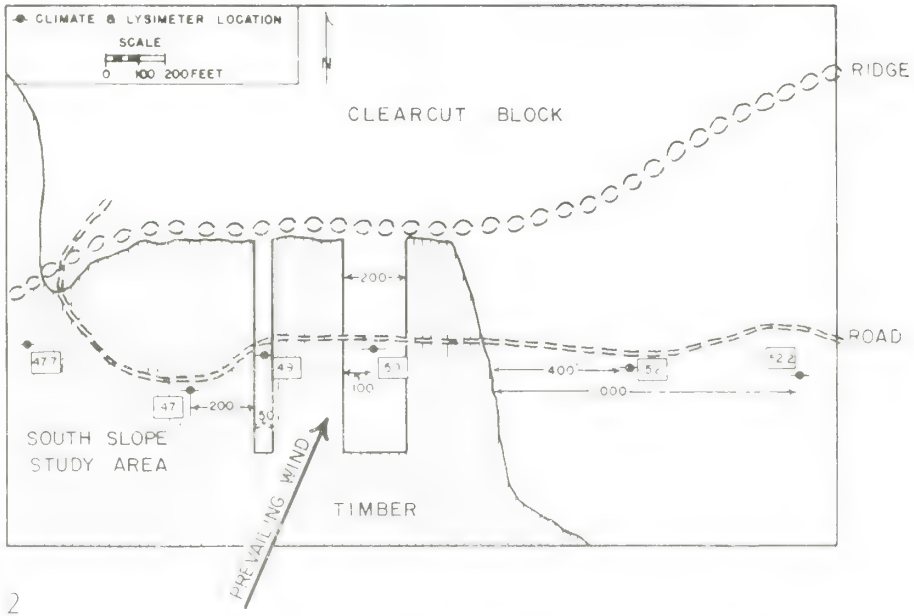
The descriptive character of each clearing and control site is given in table 1. Schematic diagrams in figures 1, 2, and 3 show how far each station is from the west edge of forest. It is important that the strip cuts opened onto the clearcut blocks whereas the clearing with station N39(0) was surrounded by trees.

Table 1

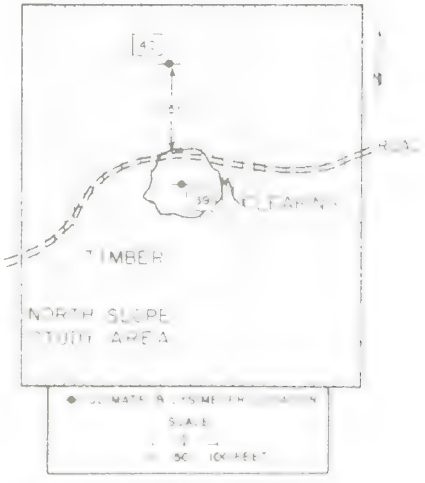
				Description of station site				
	Inclination	Snow station	Size of clearing	Type of clearing				Year of record
	30				Lysimeter-86			1968-7
						Tall tree heights, 120-150 ft,		
							skidding	73
			oriented N-S				Tractor pile and burned	
				block			burn	1968-
				Irregular block	1,000			
	1					Pole-size tree heights, 40-60 ft, surrounding)		1970-73
						heights, 100 ft; crown closure (38		73
			50x650 ft long axis	Rectangular				1969
			200x650 ft, oriented N-S				skidding	
				block			Broadcast	73
			25 acres	block			Broadcast	1970


NORTH SLOPE STUDY AREA
TIMBER
ROADS
CUT STRIPS
42
44
45
46
200'
100
200'
400
25
50
CLEARCUT BLOCK
46.6
1000'
PREVAILING WIND
N
CLIMATE & LYSIMETER LOCATION
SCALE

1


CLIMATE & LYSIMETER LOCATION
SCALE
0 100 200 FEET
N
RIDGE
CLEARCUT BLOCK
ROAD
200'
400'
100
30'
SOUTH SLOPE
STUDY AREA
TIMBER
PREVAILING WIND

2


TIMBER
NORTH SLOPE
STUDY AREA

3

MEASUREMENT TECHNIQUES

Each year of study, all precipitation was measured from November 1 through May 31. Snow courses, recording rain gages, and snow lysimeters were located at or near each station. Two parallel snow courses, each following the contour, crossed the area adjacent to the stations. They began in the clearcut block, ran across the strip cuts and contiguous leave strips, and ended well in the forest. Each course included 48 snow sampling points. Snow conditions at stations N39(0) and N40(T) were sampled, along snow courses, with six sampling points each. Water equivalent (W.E.) was measured periodically with a federal snow sampler during the accumulation-melt period, but only those readings taken at peak snowpack are discussed.

Precipitation in the clearings and throughfall and drip in the forest were measured by a recording rain gage. A single gage was placed midway across the cut strip or at predetermined distances from the edge of the forest (see table 1, Distance to (west) edge of timber). The gage in the forest was placed beneath canopies that best represented surrounding conditions. Prior to autumn 1970, gages were equipped with standard horizontal orifices and windshields. These were replaced with stereo orifices and tilted windshields (fig. 4) when it became evident that considerable precipitation was not being caught in the south aspect gages (Haupt 1972a).

Percolate was collected by snow lysimeters (Haupt 1969, 1972a) operated from November 1 through May 31. Lysimeters were positioned near the rain gages. In the forest, they were located beneath a canopy configuration similar to that above the rain gage. Lysimeters provided point measurements of net precipitation--precipitation that percolated through the snowpack during rainy periods or ultimately entered the soil mantle as the snowpack melted. A lysimeter is shown in late fall in figure 5A and in late winter in figure 5B.

Windspeed was measured with a 3-cup totalizer at each climatic station location.

Not every station was activated the fall of 1968. The south aspect replication came into operation 1 year later. Three stations, N46.6(0), S47.7(T), and S52.2(0), had lysimeters only. Years of total record are presented in table 1.

Figure 4.--Precipitation and anemometer station 52 located in large clearing (windward aspect).

is a separating layer of polyethylene.

DATA COMPILATION

Data for individual station-year [illegible] surface wind, table A2-maximum snow deposition, table [illegible] table A1-seasonal percolation) for those [illegible] by-station, year-by-year average variation. [illegible] well as those corrected for wind are shown in table [illegible] modeled and discussed in the main text.

The study design did not include [illegible] site differences existed. However, [illegible] means are large and intuitively [illegible] pretine difference of less than [illegible] differences.

PARAMETRIC MODELING

The climatic parameters--surface wind, maximum snow deposition, seasonal precipitation, and seasonal percolation--were thought to relate to the divergent conditions existing on north and south aspects and to distance away (or downwind) from the edge of forest. The four basic relationships may be expressed for the individual climatic parameter as:

$$V_s = f(D)$$
$$W.E. = f(D)$$
$$\Sigma P = f(D)$$
$$\Sigma I = f(D)$$

where V_s is mean seasonal windspeed approximately 6 feet (1.8 m) above the snow surface; $W.E.$ is snow water equivalent at time of maximum depth; ΣP is the total seasonal precipitation; or ΣI is the total seasonal percolation and D represents the horizontal distance from edge of forest in feet.

Sets of linear models were derived for most aspect conditions and are shown with corresponding R-squares in Table 2. Two south aspect conditions could not be mathematically modeled to an acceptable degree of accuracy.

Table 2.--*Models for predicting seasonal windspeed, maximum snow deposition, seasonal precipitation and percolation on two major aspects*

Aspect	Model	r^2	$S_{y.x}$	F
	Seasonal Windspeed			
North	$V_s = 2.2299 - 0.6413\ (\frac{1}{D+1}) + 0.00532(D+1)$	0.806	0.281	31.078
South	$V_s = 4.9482 - 2.4097\ (\frac{1}{D+1}) + 0.00347(D+1)$	.823	.509	30.243
	Maximum Snow Deposition			
North	$WE = 2.2704\ D^{0.229495}$	.680	.043	34.031
South	No model derived			
	Seasonal Precipitation			
North	$\Sigma P = 1.06371\ D^{0.43714}(0.99977)^D$	.986	.062	491.593
South	$\Sigma P = 1.1988\ D^{0.4079}(0.9972)^D$	.869	.363	29.859
	Seasonal Percolation			
North	$\Sigma I = 0.05494D - 0.000045\ D^2$	.924	5.674	104.115
South	No model derived			

EFFECTS OF TOPOGRAPHY AND FOREST CLEARING ON LOCAL CLIMATE

Surface Wind

Table 3 shows the mean seasonal windspeed [illegible] edge of forest. These are average value [illegible] period, therefore the speeds are small. Nevertheless, the overall mean windspeed was nearly two-thirds greater on the south (windward) aspect than on the north (lee) aspect. The differential was even greater for stations farthest from the forest edge (table 3).

The line plots of windspeed derived from equations in table 2 are shown in figure 6. Shape of the curves resembles those of Reifsnyder (1955) in his study of profiles downwind from a small isolated forest stand. Despite the limited number of stations, the models fit the data reasonably well except for one outlier, north station N39(0). That station was plotted separately in relation to the control, north station N40(T). Station N39(0) is completely surrounded by tall timber, which greatly restricts the freedom of air movement; the cut strips are incompletely surrounded, which allows more surface air movement.

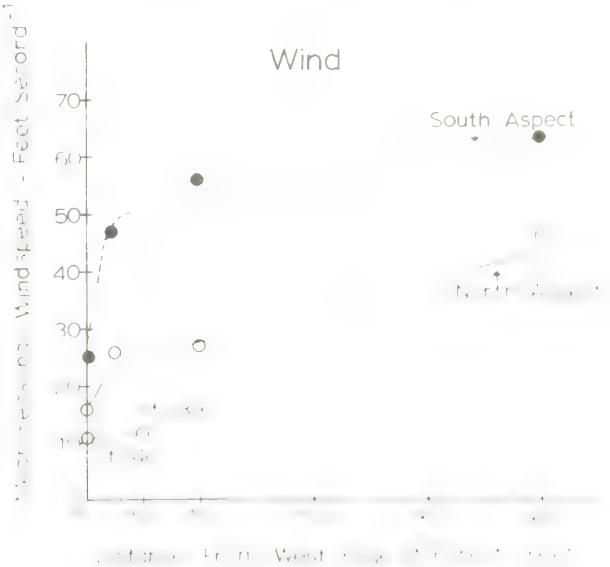


Figure 6.--Mean seasonal windspeed by aspect. Closed circles represent south stations, open circles represent north stations.

Summary.--Aspect differences in windspeed were pronounced. Larger openings in the timber were associated with greater windspeed regardless of aspect. Trees that completely circumscribed a small clearing greatly reduced windspeed across the opening.

Maximum Snow Deposition

Snow water equivalent measured at the peak during late winter has been the traditional approach for evaluating site differences under wintertime conditions. Average date of maximum depth on north aspect occurred on March 19, or 15 days later than on the south aspect. These average dates may be early because the melt season was atypical during 1972 and 1973. The long-term record for nearby Benton Creek snow course (USDA, Soil Conservation Service 1975) indicates that maximum depths apparently occur 7 to 10 days later on either aspect or mid-March on the south aspect and late March on the nort

The modeled relationship of snow deposition as a function of distance from the edg of forest (table 4) appears in figure 7; the station-by-station profiles for both aspec are plotted in figure 8.

South aspect.--Gains compared to forest conditions increased to 1.9 inches (5 cm) and then declined after a distance of 1.0 tree height away from the edge. No real gain was measured beyond 4.0 tree heights in the average year (table 4).

Table 4.--*Comparison of gains in clearings for station-years 1970-73*

Distance from west edge of timber	North	South
Feet	- - - - - - - - - *Inches* - - - - - - - - -	
	Maximum Snow Deposition (WE)	
0	0	0
25	+4.1	+1.9
	(11.	*(4.8)*
50	+5.6	
	(14.	
100	+6.6	+1.6
	(16.8)	*(4.1)*
400	+8.6	+0.4
	(21.8)	*(1.0)*
1,000	+10.8	+0.1
	(27.4)	*(0.3)*
	Precipitation (Adjusted)	
0	0	0
25	+4.70	+3.55
	(11.94)	*(9.*
50	+4.50	
	(11.93)	
100	+8.22	+5.75
	(20.88)	*(14.60)*
400	+12.67	+3.32
	(32.18)	*(8.43)*
1,000		
	Percolation	
0	0	0
25	+3.55	-2.14
	(9.02)	*(5.44)*
86	+4.01	
	(10.19)	
100	+8.58	-1.84
	(21.79)	*(4.67)*
400	+13.55	+0.43
	(34.42)	*(1.09)*
1,000[5]	+11.44	-1.90
	(29.06)	*(4.83)*

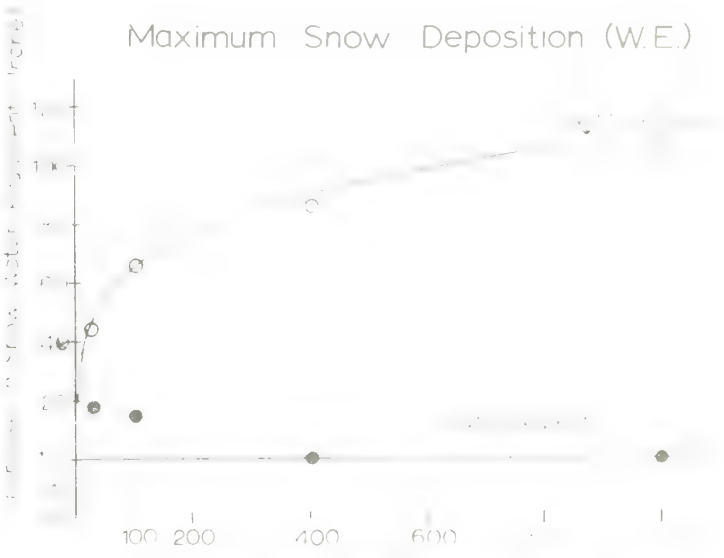
[1]North - stations 42 and 40 combined; south - stations 47 and 47.7 combined.
[2]Mean of years 1972-1973.
[3]North - stations 42 and 40 combined; south - station 47.
[4]Mean of years 1971-1973.
[5]Italicized units in centimeters.

sublimation losses from the snowpack. By assuming exposure conditions similar to those described by Agee (1968) [illegible] sublimation losses (not measured) could have been 1 to 2 inches (2 to 5 cm) greater in the larger clearings than in the north clearings and south forest.

[illegible].--This aspect [illegible] of the size of the clearing. Average gains up to 10.8 inches (27 cm) occurred in the largest clearing (table 4, figures 7 and 8).

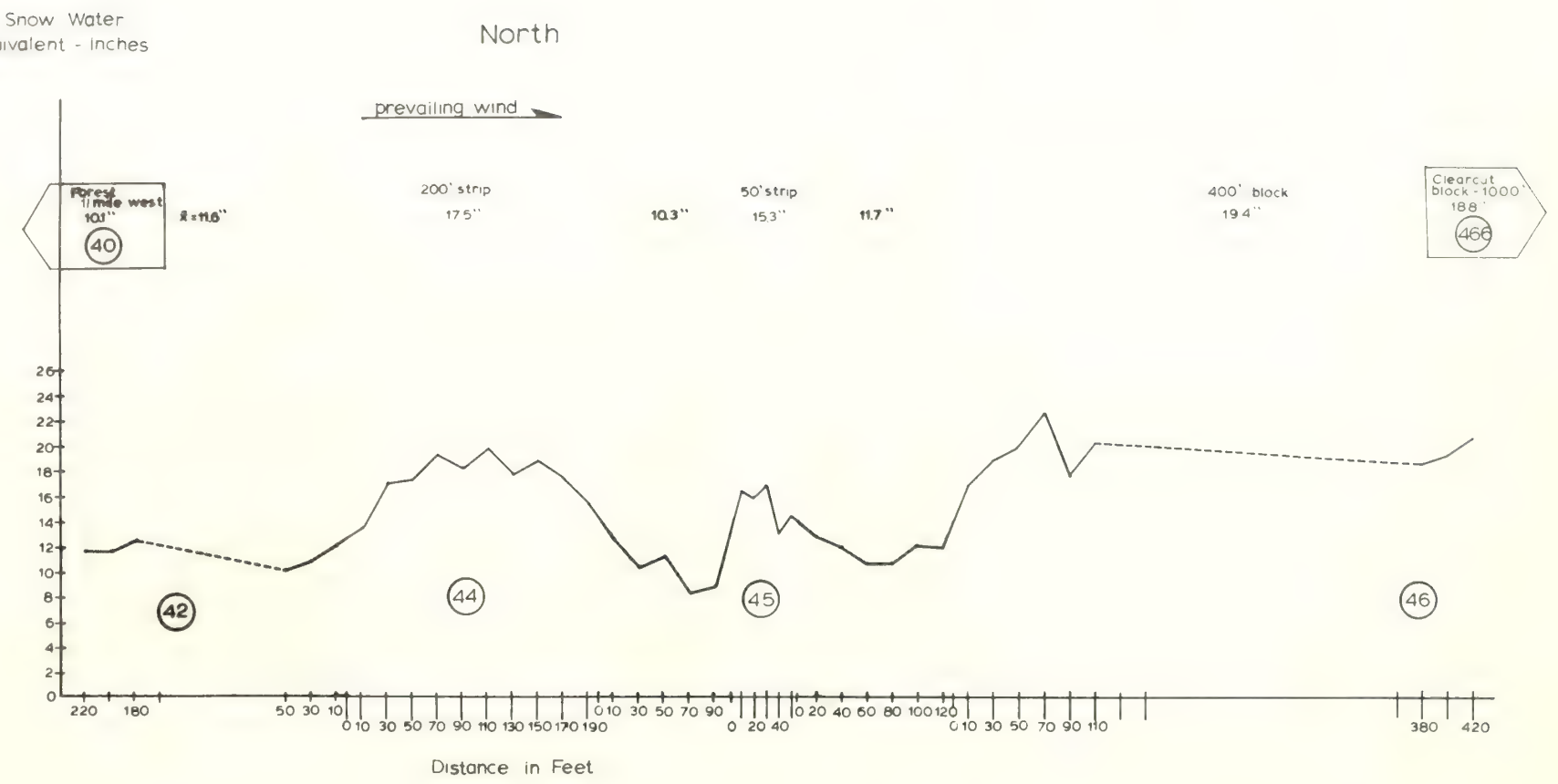
[illegible] deposition in the clearings? This question has been answered affirmatively elsewhere in studies of forest versus clearings in the high elevations of central Colorado. Hoover and Leaf (1967) concluded:

> This result [cutting treatment] did not increase [illegible] the hypothesis that the increased streamflow after treatment is brought about by decreased interception loss. Our inference from this and the actual difference in snow catch between cut and uncut strips is that while total snow catch remains the same, it is distributed differently over the watershed.



[illegible]--[illegible] tion by aspect. Closed circles represent south stations, [illegible] north stations.

[1]Parenthetic expression that of the author.


Snow Water
Equivalent - Inches
North
prevailing wind
Forest
1/mile west
10.1"
40
x̄ = 11.6"
200' strip
17.5"
10.3"
50' strip
15.3"
11.7"
400' block
19.4"
Clearcut
block - 1000'
18.8"
466
26
24
22
20
18
16
14
12
10
8
6
4
2
0
42
44
45
46
220 180
50 30 10
0 10 30 50 70 90 110 130 150 170 190
0 10 30 50 70 90
0 20 40
0 20 40 60 80 100 120
0 10 30 50 70 90 110
380 420
Distance in Feet

South

Snow Water
Equivalent - Inches

prevailing wind

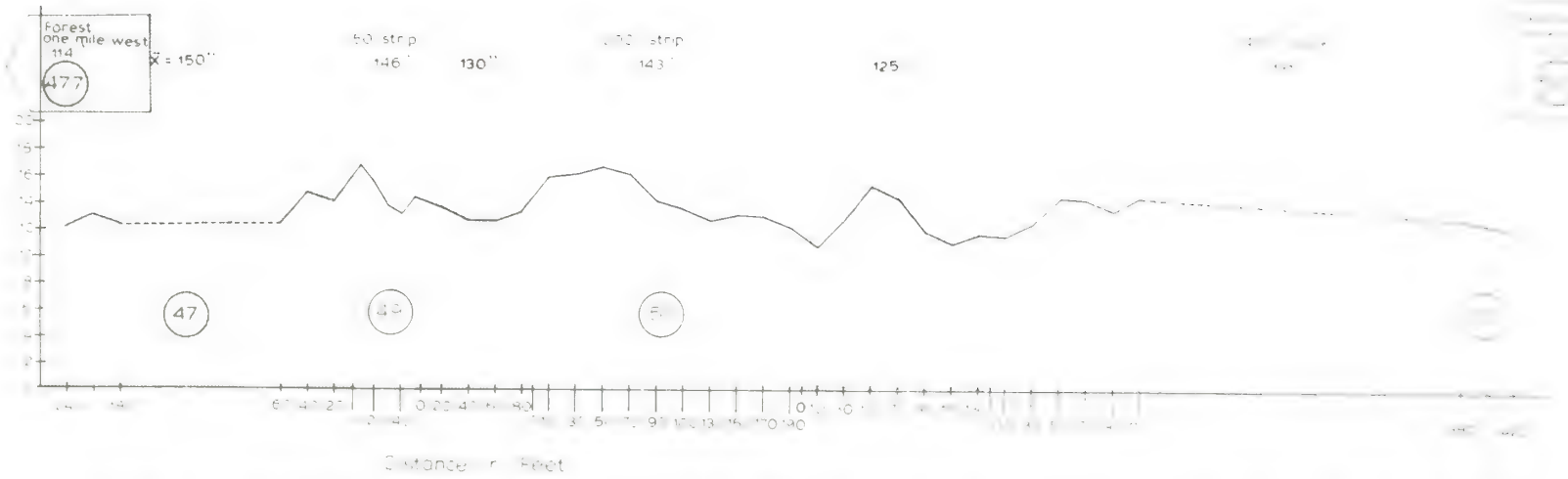


Figure 4.--Snow-water equivalent profile in spruce plantation 1, south edge.

There is less snow held by the forest covered strips and more in the openings than there was before treatment. The reason for this redistribution is the effectiveness of the openings in trapping snow transported from the intervening forested strips. Before cutting, wind action sifted snow through the forest canopy and tended to accumulate it on the ground in numerous, rather evenly distributed, small, natural openings. After cutting, the resultant openings are effective snow traps and the wind stress on the remaining forest canopy is increased. This has caused the removal of some snow that formerly settled in the forested strip to the adjacent open areas.

Other researchers working in Colorado (Dietrich and Meiman 1974; Gary 1974) and in central Sierra Nevada (Smith 1974) support the Hoover-Leaf hypothesis. Gary, in particular, concluded that greater W.E. in a small isolated clearing 1.0 tree height wide by 5.0 tree heights long (35 by 160 ft or 11 by 49 m) must be weighed against decreased W.E. in the adjacent downwind forest.

Our measurements of snow taken at four different locations in the forest (see below) do not support the Hoover-Leaf hypothesis.

Forest-station N40 (T) [1 mile (1.6 km) upwind from station N42(T)]	*Forest-station N42(T)*	*Forest leave-strips*	
		No. 1	*No. 2*
Maximum W. E. inches			
10.1 (25.6 cm)	11.6 (28.7 cm)	10.3 (26.2 cm)	11.7 (29.7 cm)

Increased wind stress carries snow from canopies close to the forest edge to adjacent openings. If this process were operative, the measurements near the forest edge (station N42(T) and particularly in the narrow, windswept leave-strips (see above and fig. 8) should reflect a sharp decrease. Instead, the three locations have W.E. values in inches comparable to the measurement taken deep in the forest (station N40(T)), 1 mile (1.6 km) upwind and quite removed from the far-distant forest edge near station N42(T). (Variations among the four values shown are considered the normal "noise" for snow measurements taken in the forest.)

Comparison of records in forest and small clearings as well as weekly observations indicate that snow on the more protected north aspect tends to persist on mature trees--sometimes for several weeks. Unlike snow in the higher and colder Colorado Rockies, very little is blown from the canopy. When snow is dislodged, it usually falls to the forest floor in massive wet clumps (Haupt 1972b).

Because the Hoover-Leaf hypothesis does not seem appropriate for Priest River conditions, other processes such as interception loss from evaporation or sublimation of canopy-held snow and wind eddy-forest-edge effects during storms appear to be operative.

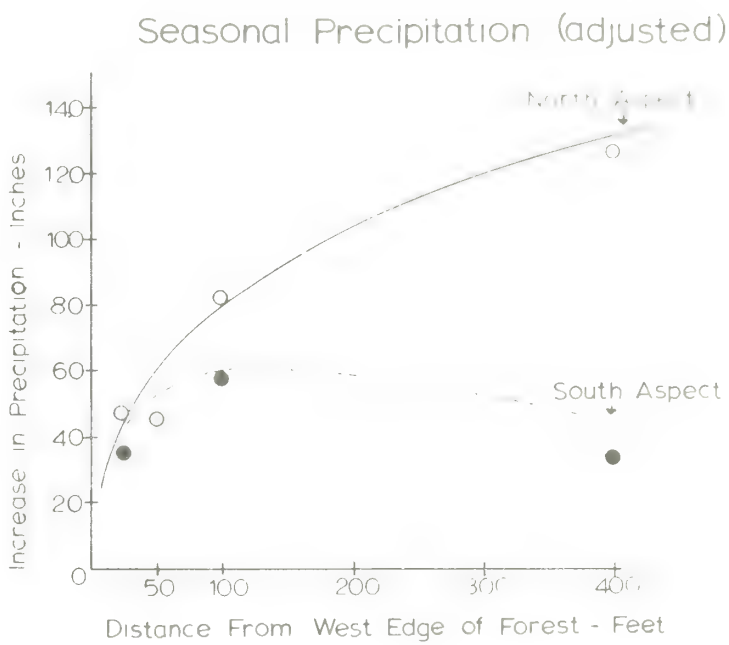
Summary.--On the south aspect, buildup in snow W.E. was restricted because of losses by wind scouring and perhaps by evaporation or sublimation. These factors had minimal influence on the north aspect as evidenced by the accumulation of large depths of snow W.E., especially in the wider clearings. The processes influencing this buildup appeared to be different from those in the higher elevation forests of Colorado and California.

Seasonal Precipitation

Early investigators recognized that gage-catch deficiencies were proportional to wind velocity (U.D. Army, Corps of Engineers 1956). The Central Sierra Snow Laboratory developed linear adjustment factors based specifically on mean winter windspeed. These

factors are used to correct wind-related [illegible] A5). A reference table showing the factors [illegible].

[illegible].--The decline in seasonal [illegible] downwind. At 4.0 tree heights, total catch is no greater than recorded for the 50 foot (15 m) wide strip (table 4 and fig. 9).



[illegible] tion (adjusted) by aspect. Closed circles represent south stations, open circles represent north stations.

North aspect.--Inspection of the relative gains (table 4) and of the plot of the gains against distance from edge of forest (fig. 9) reveals that the effect of clearing on the north aspect resulted in a positive exponential increase in catch. Increases of more than 13 inches (33 cm) were recorded at distances of 2.7 tree heights from the edge of forest. Although we made no measurements, we assumed that totals would decline beyond 3.0 tree heights. This is suggested by the decrease in percolation measured at lysimeters located beyond 3.0 tree heights.

What factors may be associated with increases in catch? Do these increases result from savings in interception loss and (or) from local wind eddy-forest edge effects during storms as well?

Discussion.--Fedorov and Burov (1967) offered the hypothesis, supported by considerable evidence, that local wind eddy-forest edge effects are important. They developed a rationale for defining an "ideal" clearing of optimum dimensions (in terms of angle of shielding of the horizon) where the most reliable amount of precipitation falls. If the clearing was too large or too small, differences occurred in the amount of precipitation measured.

They reported that the increase in error for clearings of large dimensions (angle of shielding of <20°) can be explained by the influence of aerodynamic conditions. This influence is manifested in a slight expansion of the storm-bearing streamlines over such a clearing and in the slowing of the main stream promoting excess precipitation. On the deficit side, the expansion of the streamlines is less pronounced over small clearings with an angle of shielding of greater than 45°. In such clearings during strong winds, snow (or rain) falls at an oblique angle; so part of the precipitation is intercepted by bordering trees and does not enter the receiving surface of a rain gage. Thus, the ideal clearings, where the same amount of precipitation falls as in the surrounding forest, are those that are shielded from the horizon at an angle of 30° to 45°.

The Fedorov-Burov description of ideal clearings agrees with an earlier evaluation of gage exposures conducted by Brown and Peck (1962) in Utah. Brown and Peck subjectively described the best or optimum opening for siting a rain gage, as being "well-protected" or sheltered in all directions (a) by objects subtending angles of 20° to 30° from the gage with none greater than 45° and (b) by objects of sufficient breadth to minimize eddy effects.

The criteria developed by Fedorov and Burov and by Brown and Peck were applied to the north aspect stations as shown:

Station	*Angle of shielding of the east and (or) west horizon*	*Comparison of precipitation gains in clearings (Inches)*	*Comparison of maximum snow deposition (W.E gains in clearings (Inches)*
N42(0) (forest)	90°	0.0	0.0
N45(0) (clearing)	65°	4.70	4.4
N39(0) (clearing)	49°	4.50	5.6
Ideal→N44(0) (clearing)	42°	8.22	6.6
N46(0) (clearing)	14°	12.67	8.6

The precipitation gains, as well as maximum W.E. gains, correlate reasonably well with the Fedorov-Burov hypothesis: stations N45(0) and N39(0) are apparently overshielded (too little precipitation catch), station N46(0) is undershielded (too much catch), while station N44(0) represents (with some reservations) the "ideal" clearing. Station N44(0), unobstructed by trees on its south boundary, may be undershielded in that direction. Notwithstanding this limitation, and if we assume that precipitation measured in the clearing approximates that falling into the forest, the gain of 8.22 inches (21 cm) may about equal or slightly exceed interception loss associated with old, climax stands (cedar-hemlock habitat type) on north aspects. By expanding this logic, gains registered at stations N45(0) and N39(0) represent an underestimate of interception loss, and the gain observed for station N46(0) includes the increment of interception loss plus an increment of 4 or 5 inches (10 or 13 cm). This last increment may represent excess precipitation caused by wind eddy-forest edge effect during storms.

The snowpack gain of 6.6 inches (17 cm) measured at station N44(0) offers further evidence of the magnitude of interception loss. Likewise, the snowpack gain observed for station N46(0) includes interception loss plus an additional 2 inches (5 cm). The last may represent excessive snow deposition (precipitation). However, the snow gains at stations N44(0) and N46(0) constitute net precipitation and therefore are underestimates compared to gains measured by the precipitation gages. Underestimates resulted from differential losses before April 1 due to winter melt, percolation, and evaporation and sublimation.

The following questions remain: At what point downwind from station N46(0) does deficit precipitation balance excess precipitation? Or, is the excess precipitation at station N46(0) merely the deficit precipitation that did not fall in the large south aspect clearing?

Summary.--Precipitation totals on the south aspect openings declined after 1.0-2.0 tree heights downwind. Precipitation totals on the north aspect increased with distance from the forest edge to at least 3.0 tree heights. There seemed to be an opening of optimal size where the same amount of precipitation fell as fell over the forest.

rom 7 to 8 inches (18 to [illegible]
limax stand on north aspects. On small clearings, [illegible]
ient by about 4 inches (10 cm), whereas on [illegible]
excess of about 1 inches (10 cm).

SEASONAL, MONTHLY, HIGHEST DAILY AND MEAN DAILY PERCOLATION

Seasonal Percolation

Percolation measured by the lysimeter represents net precipitation avail[illegible] nfiltrate the soil surface. On the north aspect, the general pattern of per[illegible] gains closely resembles that of precipitation gains, although individual tota[illegible] slightly less in smaller openings and slightly greater in the larger openings (table 1). These apparent differences may not be important because correction factors we[illegible] to adjust precipitation.

Lysimeter results on the south aspect were totally unlike those on the n[illegible] (fig. 10). Here seasonal deficits rather than gains were measured for the average year at each station in the clearing except station S52(0), where a small gain occurred. In individual years, there were small increases in other south aspect clearings. In one year, however, the gain was never greater than 2 inches (8 cm).

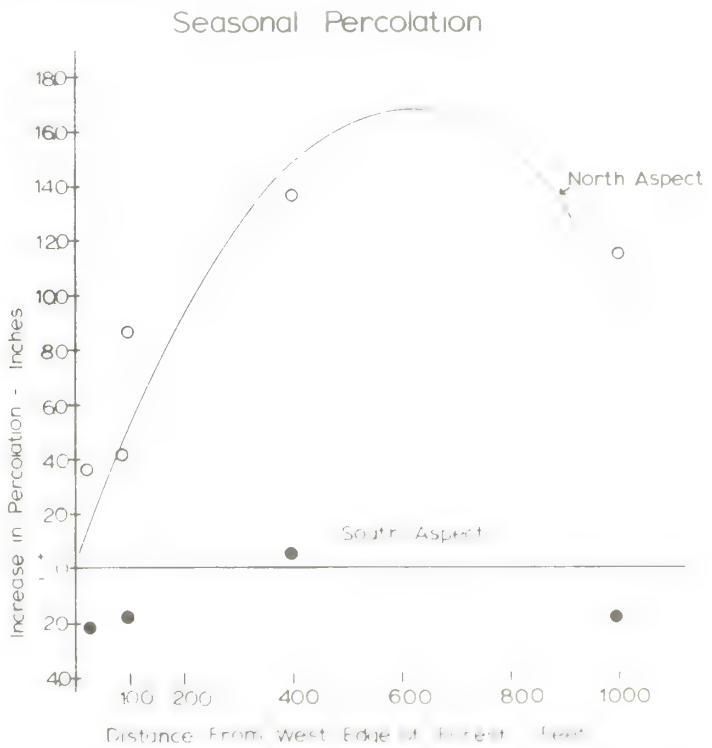


Figure 10.--Seasonal percolation by aspect. Closed circles represent south stations, open circles represent north stations.

There are important sources of water loss associated with the larger south-aspect clearings during and between storm periods. [illegible] and others (1977).

Summary.--The general pattern of [illegible] was similar to that of precipitation gains (corrected for wind).

Monthly Percolation

Under average conditions, percolation occurred at each station in every month of study (fig. 11). For some individual year-month combinations, snowpack temperatures were too low to permit release of water from the snowpack (appendix C).

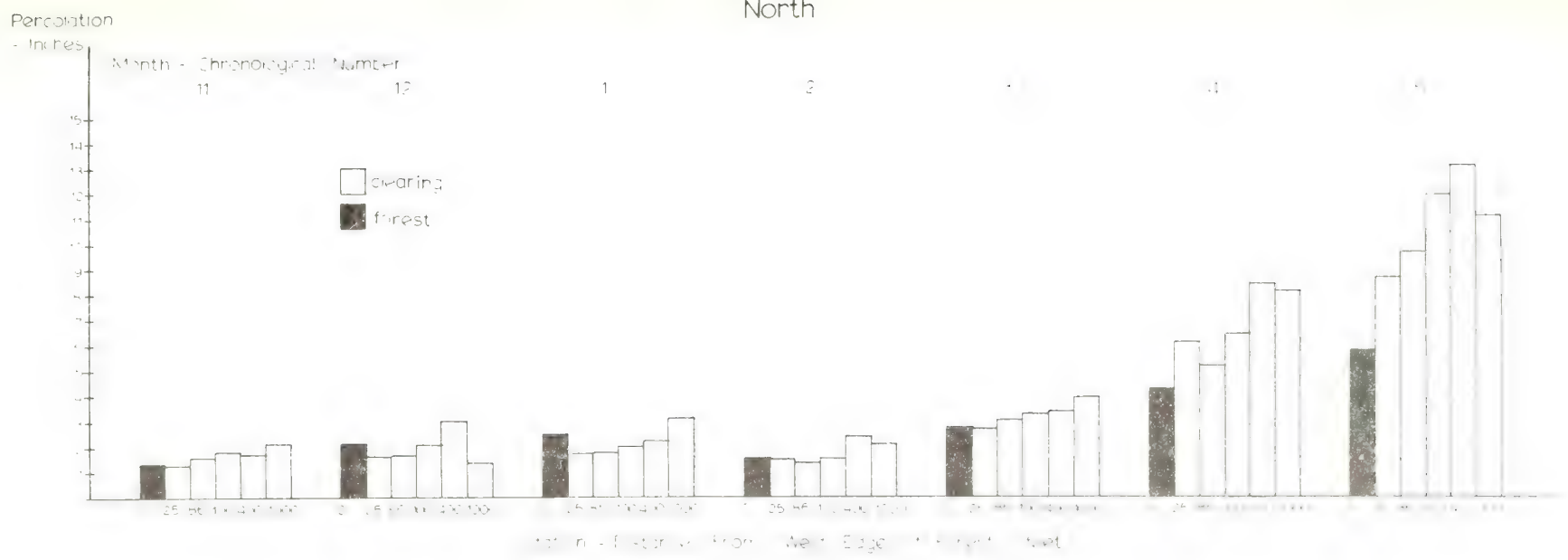
In cool winter months--November through February--the snowpack in the north forest usually released more water than the snowpack in the smaller openings (25, 86, and 100 feet or 8, 26, and 30 m wide). Only in large clearings (400 and 1,000 feet or 122 and 305 m wide) was percolation greater. With few exceptions, less water was released from openings on the south aspect than from openings in the forest.

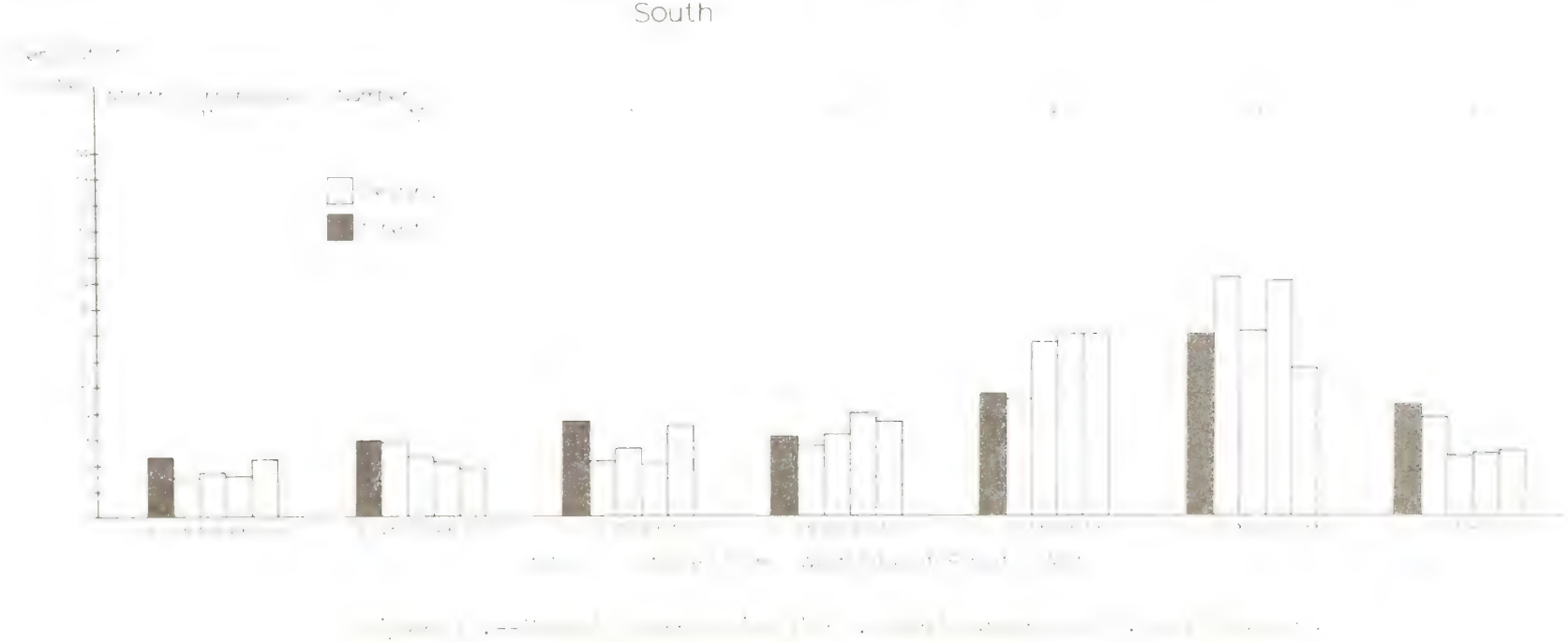
Drip originates in the canopy and contributes to the release of water or percolation in the forest during winter. This phenomenon is more evident tree for tree in the south forest because of the greater influx of energy (Haupt 1972b).

By March, the snowpack melts rapidly in larger clearings, particularly in those on the south aspect. As a consequence, monthly percolation is faster than in the shaded forest (fig. 11).

By April and May, monthly percolation in the large north clearing far outstrips that in the forest because of deeper snowpacks and greater daytime melt. The reverse condition prevails on the south aspect where snow generally disappears in the large clearings by May, but persists in the forest. Consequently, monthly percolation for May is greater in the forest (fig. 11).

Summary.--Water generally drains from the snowpack in every month of the winter. Because of drip contribution from foliage, snowpacks under timber drain more water than snowpacks in the clearings, except in the larger openings on the north aspect. The reverse situation occurs by March on the south aspect and by April on the north aspect: because of greater energy flux, more water drains from clearings than under the forest.


North
Precipitation
- Inches
Month - Chronological Number
11
12
1
2
clearing
forest


South

Highest Daily Percolation

Does clear weather snowmelt or rain with snowmelt (rain on snow) produce greater daily totals of percolation in the Experimental Forest? Does the size of clearing have an effect?

For the study period, the 35 highest ranking daily outflows of clear weather snowmelt and of rain with snowmelt on the north aspect and the 28 highest on the south aspect (1 year less of record) were averaged. Stations S52.2(0), S47.7(T), and N46.6(0) were excluded from the analysis because of too few years of data. The highest daily totals for each station event are listed in appendix D, but only the mean values will be discussed (table 5).

Table 5.--*Highest daily percolation, in inches*

Event	Distance from west edge of forest, in feet					
	400	100	86	25	0[1]	0[2]
			North[3]			
Snowmelt	1.40 *(3.56)*[4]	1.22 *(3.10)*	1.05 *(2.67)*	1.08 *(2.74)*	0.96 *(2.44)*	0.68 *(1.73)*
Rain with snowmelt	1.26 *(3.20)*	1.02 *(2.59)*	0.91 *(2.31)*	1.00 *(2.54)*	0.91 *(2.31)*	0.89 *(2.26)*
n=35						
			South[5]			
Snowmelt	1.10 *(2.79)*	0.95 *(2.41)*		0.91 *(2.31)*	0.98 *(2.49)*	
Rain with snowmelt	1.16 *(2.95)*	1.01 *(2.57)*		0.99 *(2.51)*	1.23 *(3.12)*	
n=28						

[1]North - station 42; south - station 47.
[2]North - station 40.
[3]Years - 1969-1973.
[4]Italicized units in centimeters.
[5]Years - 1970-1973.

North aspect.--Except at station N40(T), the 24-hour daily snowmelt exceeded the 24-hour rain with snowmelt in the forest. This is also true of all stations in the clearings. For both weather events, the relationship was the same: the greater the distance to the middle of a clearing, the greater the daily percolation. This would be expected with snowmelt because of greater energy flux in the larger clearing and with rain with snowmelt because more precipitation falls in the larger clearing.

However, a timing delay contributed to higher snowmelt totals. Normally, the snowpack persists until late in the season and, therefore, responds to the increased energy flux common to nonrainy periods in late spring. Highest daily snowmelt invariably occurs in the last 6 to 10 days before snow disappears in May. The highest 24-hour totals of rain with snowmelt are associated with warm, rainy storm fronts that move across Idaho in November, December, and January.

North aspect.--The melt picture is more complex. For openings, we find that daily snowmelt increases as the distance from edge of forest increases. However, daily snowmelt in the forest is greater than in the clearing, except station 52. This high melt rate for the forest follows a time-delay relationship. The snowpack shaded by the forest lasts longer, usually into May, and so may receive a greater energy flux.

On the south aspect, the most elevated, 24-hour total (1.23 inches or 3.12 cm) occurred as rain with snowmelt in the forest. Our lysimeter records indicate that this total includes a large increment of drip, which is associated exclusively with trees.

Based upon per unit of crown projection, the south forest has the capability of producing more percolation in a 24-hour period than the north forest. For openings in general, greater percolation totals can be expected in north clearings than in south clearings.

Summary.--The highest daily percolation rates usually are associated with snowpacks in clearings rather than those under the forest. There is one exception, the south aspect forest. Here the drip contribution can be phenomenally high because the energy flux associated with sunny, windswept slopes is greater than in the forest. Only in the largest clearings on the north slope do daily rates exceed those in the forest on the south aspect.

Mean Daily Percolation

Mean daily percolation was determined by a two-step procedure: the first step was to select a beginning date, time = day 1. For the winter period, time = day 1 was November 1. The second step was to accumulate consecutive days of percolation through February 28 (time = day 120) and then to divide by 120 to calculate the mean daily rate. For the spring period, time = day 1 was March 1 and the mean daily rate was based upon the number of days up to and including the final day of melt. Mean rate by year, aspect, and station are listed under appendix E; table 6 displays mean rates for combined years 1971-73.

On both aspects, from November 1 through February 28 mean rates in the forest equaled or exceeded those in the clearings except for north station N46(0). The high mean rate in the forest was due primarily to the drip component. After March 1, the percolation rate pattern reversed; rates in the clearing equaled or exceeded those in the forest because of more exposure to energy sources.

Table 6 shows April 6 in the average year as the last day that snow was present at all stations. Mean rates on April 6 were greater at each location on the south aspect than on the north aspect. This relationship held whenever the snowpack was on both aspects. (A comparison of the means of two different stations must be calculated the same day to be valid.)

After March 1 mean percolation rates in all but one of the clearings surpassed those of the forest as long as snow remained in the clearing and forest. The exception, north station N39(0), sometimes had rates no greater than those in the adjacent forest, which suggests that the wind and the shading effect kept melting to a minimum.

Table 6.--Mean daily precipitation during winter and spring periods, in inches, for years 1973-77

Season/date	Distance from west edge of forest												
	1,000	400	100	25	0[1]	0-	1,000	400	100	86	25	0[2]	0-
	SOUTH						NORTH						
Winter													
November 1 through February 28	0.09	0.08	0.09	0.08	0.11	0.10	0.07	0.09	0.07	0.06	0.06	0.07	0.07
Spring													
March 1 through:													
April 6	.29	.31	.28	.21	.24	.17	.14	.14	.14	.13	.12	.11	.12
	Bare		Bare										
10		.35		.24	.26	.18	.16	.16	.15	.12	.14	.12	.13
11		Bare											
18				.26	.25	.18	.15	.15	.15	.12	.13	.12	.12
19					Bare								
20				.27		.19	.15	.15	.14	.12	.14	.12	.12
21				Bare									
26						.23	.18	.19	.17	.14	.16	.13	.13
27						Bare							
29							.20	.23	.19	.16	.19	.15	.15
30													Bare
May 2							.25	.27	.22	.18	.22	.18	
3												Bare	
4							.25	.27	.23	.19	.23		
5											Bare		
7							.28	.29	.26	.21			
8							.29	.31	.26	Bare			
9							.29	Bare	.27				
10									Bare				
11							.29						
12							Bare						

[1]South - station 47; north - station 42.
[2]South - station 47.7; north - station 40.

Summary.--On snow-covered north and south aspects, mean daily rates of melt are always greater on south slopes regardless of the degree of forest removal. Small, well-protected clearings on the north aspect do not increase mean daily rates significantly over those in the surrounding forest.

Snow Disappearance

Ground surface became bare of snow earliest in the larger south aspect clearings (table 6) some 7 to 11 days after April 1 (table 7). Snow melted in the south forest an average of 10 to 16 days later. Early snowmelt in the clearings resulted from (a) lack of a deep snowpack at the beginning of melt and (b) higher average melt (or percolation) rates than those in the forest.

Table 7.--*Mean elapsed days after April 1 before snow disappearance in lysimeters, years 1971-73*

Slope	Distance from west edge of forest, in feet						
	1,000	100	100	80	25	0	40
South	7	11	7		21	19	25
North	12	39	40	38	35	35	30

[1]North - station 42; south - station 47.
[2]North - station 40; south - station 47.7.

In sharp contrast, a much deeper snowpack had been deposited in the north clearings by the start of spring melt. In spite of higher melt rates, north clearings usually kept their snow covering 2 to 12 days longer than the forest floor.

A comparison of stations S47(T) and S47.7(T) in the south forest showed that 47.7, the more shaded of the two, kept its snow 8 days longer. In the north forest, canopies over stations N42(T) and N40(T) were nearly alike. However, station 40 was approximately 300 feet (91 m) lower in altitude which may explain why snow disappeared 3 days later at the higher station (table 7).

Summary.--Generally, the greater the distance from the edge of forest the later snow persisted on the north aspect and the sooner it disappeared on the south aspect. Also, the denser the forest cover on the south aspect, the longer the snow cover remained.

SNOW DEPTH, SNOW DENSITY AND BIG GAME MOBILITY

Winter represents the critical time of year for big game because snow can severely hinder animals searching for shelter and forage. Big game biologists claim two properties of the snowpack--depth and density (hardness)--are of paramount influence. Table 8 shows approximate threshold depths of soft snow at which mobility becomes difficult for the four major big game animals of northern Idaho. Note that moose can move about in twice the depth of snow as the lithe, fleet-footed mule deer.

As the snow density increases so does the mobility problem. Nasimovich (1955) described in considerable detail the effect of various snow densities. For instance, if snow is loose and powdery with low densities ranging between 0.15 and 0.20, large mammals can run without difficulty in greater depths than those shown in table 8. If the densities are in the 0.21 to 0.22 range, snow impedes the animals' movements. If densities range between 0.24 and 0.26, animals do not sink as far into the snow, but it is more difficult for them to lift their feet from the hole in the snow to take another step.

Snow of very high density (crustiness) can also hinder the animal in moving about, according to Kelsall and Prescott (1971). Many crusts are hard enough to support walking animals and some, but not all, do so. Animals that break through can lacerate their feet and legs on sharp edges.

Table 8.--*Approximate depth of soft snow when mobility becomes difficult for large mammals*

Mammal	Snow depth threshold	Literature reference
	Inches	
Mule deer	18	Gilbert and others 1970
Moose	37	Nasimovich 1955
Caribou	24	Pruitt 1959
Elk	22[1]	Kelsall and Telfer 1971; Kelsall 1969

[1]Calculated from analogous data.

When snow is deepest in the Priest River study area, large mammals would find the going impossible on the north aspect, especially in clearings. In winters such as 1973, when snowfall is low, it might be feasible for them to move through the forest (table 9). Mobility here would be easier with the slightly lower densities associated with the shallow 1973 snowpack (table 10).

On the average, conditions on the south aspect are slightly better, but only in years of low snowfall, such as 1973. In such winters, the large, windswept opening as well as the forest sites offer more favorable snow depths. However, densities would be high and the excessive crustiness associated with south exposures might be impeding.

Early melt is a south-aspect attribute. The large south-aspect clearing melts soonest and so shrub forage appears much earlier there than on other sites.

Table 9. - [illegible]

Aspect/ year	Approximate day of occurrence	Distance from west edge of forest, in feet					
		1,000	400	[illegible]	50		
North							
1970	3/25		[illegible]	61	58	[illegible]	44
1971	4/1		57	[illegible]	55	47	39	29
1972	3/2	56	60	54	50	[illegible]	[illegible]	[illegible]
1973	3/15	54	45	42	[illegible]	34	17	[illegible]
$\bar{M}$	3/19	55 (1.4 m)	56 (1.4 m)	[illegible] (1.3 m)	49 (1.2 m)	47 (1.2 m)	36 [illegible]	[illegible] (0.8 m)
South								
1970	3/18		38	44		47	48	
1971	3/17		46	45		52	47	
1972	2/17	40	44	47		49	46	44
1973	2/22	28	29	31		29	27	18
$\bar{M}$	3/4	34 (0.9 m)	39 (1.0 m)	42 (1.1 m)		44 (1.1 m)	42 (1.1 m)	31 (0.8 m)

[1]North - station 42; south - station 47.
[2]North - station 40; south - station 47.7.

Table 10.--*Snow density at greatest depth on north and south aspects*

Aspect/year	Distance from west edge of forest, in feet					
	1,000	400	100	[illegible]	[illegible]	[illegible]
North						
1970		0.35	0.34	[illegible]	0.34	[illegible]	0.33
1971		.36	.35	.34	.34	.35	.38
1972	0.31	.34	.32	.33	.31	[illegible]	.32
1973	.35	.33	.30	.34	.30	.32	.34
$\bar{M}$	.34	.34	.33	.34	.32	[illegible]	.34
South							
1970		.37	.34		.35	.33	
1971		[illegible]	.35		.33	[illegible]	
1972	.30	.31	.33		.32	.31	.33
1973	.29	[illegible]	.33		.29	.27	[illegible]
$\bar{M}$	.30	.33	.34		[illegible]	[illegible]	.30

[1]North - station 42; south - station 47.
[2]North - station 40; south - station 47.7.

[illegible].--The winter mobility of [illegible] in forest clearings. Ranked by relative mobility are the following: mule deer < elk < caribou < moose, the last being the most capable of moving about in deeper snow. Very high density snow (crustiness) may greatly hinder movement and in some cases injure the feet and legs of animals. Windswept openings on south aspects are bare earlier in the spring and can provide much sought-after forage.

MANAGEMENT CONSIDERATIONS

Some management considerations drawn from the results of the study are listed below. Potential users should be aware that these considerations were developed from a limited amount of data, from more unreplicated than replicated stations in two climax habitat types, and under the sequence of climatic events recorded. Any extrapolation should be done with these limitations in mind.

Creating larger openings on the north aspect will develop a high potential for increasing total water yield. On the south aspect, similar clearings located in a slope position below the ridge crest will have a minimal or even a negative effect on water yield increase.

Winter flooding caused by rain with snowmelt will be enhanced by creating larger openings on the north aspect. Because of the copious amounts of drip associated with south-aspect forests, any clearing in these forests will lessen the hazard of winter flooding.

Because of greater snow deposition and higher melt rates, large openings on the north aspect can cause higher spring peak flows for many years after logging, thus imperiling water quality. This hazard can be greatly reduced by using very small, well-shielded openings.

Larger openings on the south aspect permit a more rapid spring melt and an earlier disappearance of snow than occur in the uncut forest. In theory, by maintaining a balance between the amount of area cut and that left uncut, peak flows from a south-facing watershed would be reduced because of desynchronization of melt rates.

Big game winter range will not be enhanced by clearing old stands on the north aspect. Openings on the south aspect will benefit big game because of the early appearance of shrub forage in the springtime.

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APPENDIX A

Mean seasonal windspeed table A1, maximum snow deposition table A2, seasonal precipitation table A3, and seasonal percolation table A4

Table A1.--*Mean seasonal windspeed for each year of study*

Aspect and year	Distance from west edge of forest, in feet					
	400	100	50	25	0[1]	0[2]
	Feet second^{-1}					
North						
1969	3.4	2.5	1.2	1.9	[3]	0.7
1970	3.9	2.5	1.4	2.2	[3]	1.3
1971	4.3	3.0	1.5	2.5	1.8	1.0
1972	5.7	2.8	0.9	3.1	1.5	[3]
1973	4.6	2.5	[3]	2.6	1.5	[3]
South						
1970	5.3	4.9		4.3	2.4	
1971	6.4	6.2		5.0	3.1	
1972	7.2	6.1		5.2	3.2	
1973	6.2	5.0		4.3	1.4	

Table A2.--*Maximum snow deposition for years of study*

Aspect and year	Distance from west edge of forest, in feet						
	1,000	400	100	50	25	0[1]	0[2]
	Inches						
North							
1969		24.6	22.9	21.6	19.0	17.0	18.0
1970		22.5	20.6	19.0	18.0	15.4	14.7
1971		20.2	19.3	18.5	16.1	13.5	10.8
1972	19.0	20.2	17.4	16.7	16.5	12.3	10.1
1973	18.6	14.5	12.5	11.4	10.6	5.1	4.7
$\bar{M}$	18.8	19.4	17.5	16.4	15.3	11.6	10.1
cm		*(49.3)*	*(44.5)*	*(41.7)*	*(38.9)*	*(29.5)*	*(25.7)*
South							
1970		14.2	15.6		16.7	15.4	
1971		15.2	15.5		17.3	15.2	
1972	12.2	13.7	15.8		15.6	14.4	14.2
1973	8.2	9.3	10.4		8.8	7.2	4.6
$\bar{M}$	10.2	13.1	14.3		14.6	13.0	9.4
cm	*(25.9)*	*(33.3)*	*(36.3)*		*(37.1)*	*(33.0)*	*(23.9)*

[1]North - station 42
South - station 47.
[2]North - station 40
South - station 47.7.
[3]Anemometer inoperative much of year

Table A5.--*Seasonal precipitation (total and adjusted) for years of study, in inches*

Aspect and year	Distance from west edge of forest, in feet											
	400	100	50	25	0[1]	0[2]	400	100	50	25	0[2]	0[3]
	(Gage catch)						(Gage catch adjusted for wind)					
North												
1969	34.58	32.94	33.61	30.48	28.69	27.98	39.42	36.30	34.62	32.49	30.07	28.40
1970	27.87	26.10	25.36	24.70	21.71	20.55	32.89	28.76	26.12	26.77	22.75	21.17
1971	32.94	32.98	31.45	28.35	28.59	25.19	39.53	36.94	32.39	31.24	30.48	25.76
1972	32.97	31.79	29.92	28.58	26.25	22.92	42.86	35.60	30.59	32.01	27.84	23.64
1973	21.13	23.98	22.61	21.05	19.47	17.44	29.80	25.99	23.29	23.20	20.05	17.96
M	29.55	28.71	27.34	25.63	24.00	21.52	36.25	31.82	28.10	28.58	25.08	22.12
cm	75.06	72.92	69.44	65.09	60.96	54.66	92.08	80.82	71.37	72.58	63.70	56.18
South												
1970	15.12	15.50		15.94	18.87		21.81	24.79		25.20	28.46	
1971	21.38	24.68		25.87	25.35		28.26	32.63		29.60	28.37	
1972	24.23	24.78		24.41	22.01		30.80	32.70		30.74	25.99	
1973	17.99	19.45		18.29	16.89		23.66	24.12		21.95	17.45	
M	19.68	21.60		21.13	20.78		26.15	28.56		26.38	25.57	
cm	50.0	54.9		53.7	52.8		66.4	72.6		67.0	65.0	

North - station 4.
South - station 47.
North - station 5.
South - station 57.
[1] Modified 8-in tilted windshield and stereo orifice.
[2] Catch factor for modified shield-orifice = 0.81.

Table A4.--*Seasonal percolation for years of study*

Aspect and year	Distance from west edge of forest, in feet						
	1,000	400	100	86	25	0[1]	0[2]
	Inches						
North							
1969		40.64	35.78	31.91	32.55	33.39	28.62
1970		32.25	26.86	23.60	22.51	20.63	19.93
1971	37.09	39.57	33.23	26.62	29.64	24.90	22.47
1972	32.69	37.71	32.94	26.79	26.60	24.00	22.52
1973	26.01	26.42	23.05	20.80	17.22	15.32	13.73
$\bar{M}$	31.93	33.99	29.02	24.45	23.99	21.21	19.66
cm	*(81.10)*	*(86.33)*	*(73.71)*	*(62.10)*	*(60.93)*	*(53.87)*	*(49.94)*
South							
1970		28.17	27.36		24.68	25.93	
1971	29.90	34.12	27.61		30.83	33.13	32.37
1972	28.38	29.41	27.33		28.90	32.61	31.19
1973	21.08	21.00	21.30		17.98	20.16	20.62
$\bar{M}$	26.45	28.18	25.90		25.60	27.96	28.06
cm	*(67.18)*	*(71.58)*	*(65.79)*		*(65.02)*	*(71.02)*	*(71.27)*

[1]North - station 42
South - station 47.
[2]North - station 40
South - station 47.7.

APPENDIX B

Gage Deficiency

Table B1.--*Correction factors and gage-catch deficiencies for various mean windspeeds, after Corps of Engineers, 1956*

Mean windspeed (meters second^{-1})	Adjustment factor	Gage deficiency in percent of "true" catch
0	1.000	0
0.1	1.008	0.8
0.2	1.015	1.5
0.3	1.023	2
0.4	1.03	3
0.5	1.05	5
0.6	1.07	7
0.7	1.08	8
0.8	1.10	9
0.9	1.12	11
1.0	1.14	12
1.1	1.16	14
1.2	1.18	15
1.3	1.20	17
1.4	1.22	18
1.5	1.24	19
1.6	1.26	21
1.7	1.28	22
1.8	1.30	23
1.9	1.32	24
2.0	1.34	25
2.1	1.37	27
2.2	1.39	28
2.3	1.41	29
2.4	1.43	30
2.5	1.46	31
2.6	1.48	32
2.7	1.50	33

APPENDIX C

Monthly Percolation

Table C1.--*Monthly percolation,*[1] *north aspect, in inches*

Year	November	December	January	February	March	April	May
			1,000 feet (station 46.6)				
1971	1.78	2.39	5.43	2.74	0.18	11.45	13.12
72	3.39	0.00	1.38	2.78	7.19	4.65	13.10
73	1.31	1.82	2.62	0.65	4.27	8.39	6.95
M	2.16	1.40	3.14	2.06	3.88	8.16	11.06
cm	*(5.49)*	*(3.56)*	*(7.98)*	*(5.23)*	*(9.86)*	*(20.73)*	*(28.09)*
			400 feet (station 46)				
1969	4.62	2.03	0.02	0.26	2.97	16.91	13.83
70	0.94	2.73	1.11	0.34	0.97	5.46	20.70
71	2.08	3.50	4.61	3.05	0.53	13.79	12.01
72	2.75	0.07	1.93	5.73	8.78	5.73	12.72
73	1.12	5.84	1.27	0.50	2.25	8.65	6.79
M	1.72	3.04	2.23	2.40	3.38	8.41	13.06
cm	*(4.37)*	*(7.72)*	*(5.66)*	*(6.10)*	*(8.59)*	*(21.36)*	*(33.17)*
			100 feet (station 44)				
1969	3.64	2.05	0.02	0.00	2.49	14.22	13.36
70	0.91	2.10	0.76	0.16	0.69	4.21	18.03
71	1.90	2.31	4.34	2.01	0.36	10.20	12.11
72	3.11	0.01	2.08	3.45	9.64	3.02	11.63
73	1.27	3.76	0.91	0.63	2.30	8.26	5.92
M	1.80	2.04	2.02	1.56	3.25	6.42	11.92
cm	*(4.57)*	*(5.18)*	*(5.13)*	*(3.96)*	*(5.79)*	*(16.31)*	*(30.28)*
			86 feet (station 39)				
1969	3.51	1.65	0.07	0.17	2.30	13.97	10.24
70	1.00	1.39	0.55	0.34	0.78	3.35	16.19
71	1.63	2.30	3.42	2.26	0.50	6.80	9.71
72	2.54	0.08	1.76	2.07	7.96	2.71	9.67
73	1.25	3.68	1.42	0.72	2.88	7.85	3.00
M	1.60	1.86	1.79	1.35	3.03	5.18	9.64
cm	*(4.06)*	*(4.72)*	*(4.55)*	*(3.43)*	*(7.70)*	*(13.16)*	*(24.49)*
			25 feet (station 45)				
1969	3.47	1.97	0.13	0.02	2.68	13.11	10.90
70	0.77	1.75	0.52	0.30	0.64	3.30	15.23
71	1.33	2.25	3.58	2.11	0.36	11.22	8.77
72	2.07	0.06	1.84	3.06	8.81	3.05	7.71
73	1.05	3.31	1.08	0.71	1.07	7.05	2.95
M	1.30	1.84	1.76	1.54	2.72	6.16	8.66
cm	*(3.30)*	*(4.67)*	*(4.47)*	*(3.91)*	*(6.91)*	*(15.65)*	*(22.00)*
			0 feet (station 42)				
1969	3.62	2.93	0.23	0.36	2.77	13.02	10.46
70	0.62	2.63	1.58	0.65	0.77	2.49	11.89
71	1.56	2.42	3.68	1.81	0.48	7.88	7.07
72	1.75	0.16	2.35	2.95	7.31	3.18	6.30
73	0.92	3.80	2.07	0.90	1.41	4.39	1.83
M	1.21	2.25	2.42	1.58	2.49	4.48	6.77
cm	*(1.01)*	*(5.72)*	*(6.15)*	*(4.01)*	*(6.32)*	*(11.38)*	*(17.20)*
			0 feet (station 40)				
1969	4.11	2.00	0.25	0.34	2.74	13.55	5.63
70	0.83	2.25	1.44	0.76	1.41	2.87	10.37
71	1.64	2.50	4.28	2.00	0.62	8.40	3.03
72	1.77	0.64	2.05	2.53	8.14	4.09	3.30
73	1.46	3.03	3.01	0.96	1.74	1.29	2.24
M	1.42	2.10	2.70	1.56	2.98	4.16	4.74
cm	*(3.61)*	*(5.33)*	*(6.86)*	*(3.96)*	*(7.57)*	*(10.57)*	*(12.04)*

[1]Means exclude 1969.

Table C2.--*Monthly precipitation, south aspect,*

Year	November	December	January	February	March	April	May
				1,000 feet (station 52.2)			
1971	2.06	3.12	[illegible]	[illegible]	[illegible]	11.02	[illegible]
72	3.40	0.35	2.50	[illegible]	11.61	3.11	[illegible]
73	1.33	2.07	[illegible]	5.02	[illegible]	2.97	[illegible]
M	2.26	1.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
cm	*(5.74)*	*(4.70)*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				400 feet (station 52)			
1970	0.61	4.01	0.39	4.36	7.63	9.13	2.01
71	1.89	2.77	[illegible]	3.10	[illegible]	17.94	2.26
72	2.58	0.07	2.05	6.01	12.84	3.39	[illegible]
73	1.22	1.79	[illegible]	2.46	5.94	5.76	[illegible]
M	1.58	2.16	[illegible]	3.98	6.98	[illegible]	2.42
cm	*(4.01)*	*(5.49)*	*(5.08)*	[illegible]	*(17.73)*	[illegible]	*(6.1)*
				100 feet (station 50)			
1970	0.80	3.12	0.42	2.73	6.86	11.53	[illegible]
71	2.02	3.06	[illegible]	2.82	2.27	[illegible]	2.21
72	2.61	0.23	2.61	4.55	11.53	3.47	2.55
73	1.40	2.78	1.75	2.78	6.00	3.94	[illegible]
M	1.71	2.30	[illegible]	3.16	6.66	[illegible]	2.34
cm	*(4.34)*	*(5.84)*	[illegible]	[illegible]	*(16.92)*	*(18.08)*	*(5.94)*
				25 feet (station 49)			
1970	0.71	1.89	0.78	1.74	3.22	[illegible]	7.89
71	1.61	2.75	4.76	2.14	2.06	[illegible]	2.05
72	2.31	0.12	2.29	[illegible]	9.39	[illegible]	[illegible]
73	1.33	1.99	0.86	1.95	[illegible]	[illegible]	[illegible]
M	1.49	2.88	2.17	2.70	[illegible]	9.20	3.80
cm	*(3.78)*	*(7.32)*	[illegible]	*(6.86)*	*(11.53)*	*(23.37)*	*(9.65)*
				0 feet (station 47)			
1970	0.84	3.88	[illegible]	1.50	.02	6.77	8.69
71	3.01	3.47	[illegible]	2.99	1.48	12.97	[illegible]
72	3.28	0.08	3.09	5.60	11.73	5.70	3.15
73	1.69	4.35	2.94	[illegible]	[illegible]	3.24	[illegible]
M	2.20	[illegible]	[illegible]	2.90	[illegible]	7.17	4.18
cm	[illegible]	*(7.*	*(9.42)*	[illegible]	[illegible]	[illegible]	[illegible]
				0 feet (station 47.7)			
72	[illegible]	0.15	[illegible]	[illegible]	10.22	[illegible]	1.88
73	[illegible]	4.58	[illegible]	[illegible]	2.70	1.11	2.07
M	[illegible]	[illegible]	[illegible]	[illegible]	4.60	[illegible]	[illegible]
cm	[illegible]	*(7.*	[illegible]	[illegible]	[illegible]	*(2.*	[illegible]

APPENDIX D

Highest Daily Amounts of Percolation

Table D1.--*Highest daily percolation from clear weather melt on north aspect for years 1969-73, in inches*

Distance from west edge of forest					
400	100	86	25	0[1]	0[2]
2.05	1.97	1.84	1.83	1.98	1.51
2.02	1.89	1.76	1.81	1.84	1.35
2.01	1.80	1.63	1.81	1.65	1.09
1.93	1.57	1.63	1.64	1.57	1.07
1.81	1.50	1.46	1.60	1.38	0.95
1.79	1.47	1.42	1.56	1.34	.89
1.76	1.46	1.29	1.53	1.22	.86
1.68	1.44	1.25	1.42	1.22	.81
1.62	1.43	1.21	1.34	1.19	.80
1.61	1.43	1.09	1.30	1.18	.80
1.59	1.42	1.08	1.30	1.08	.79
1.56	1.35	1.08	1.27	1.02	.78
1.56	1.32	1.03	1.25	1.01	.76
1.47	1.31	1.03	1.21	0.94	.67
1.46	1.26	1.03	1.04	.93	.64
1.45	1.24	1.02	1.03	.89	.60
1.44	1.22	1.01	1.00	.88	.58
1.41	1.21	1.01	0.95	.82	.57
1.39	1.20	0.95	.87	.82	.57
1.38	1.20	.94	.86	.78	.56
1.33	1.16	.92	.85	.76	.54
1.25	1.12	.91	.84	.75	.53
1.21	1.05	.88	.84	.75	.52
1.19	1.01	.87	.80	.73	.52
1.12	0.98	.87	.75	.71	.52
1.05	.98	.85	.75	.71	.50
1.00	.93	.85	.74	.68	.50
1.00	.92	.81	.73	.67	.47
0.98	.91	.80	.70	.64	.46
.98	.89	.77	.70	.63	.46
.96	.87	.75	.69	.61	.45
.96	.86	.71	.68	.61	.45
.95	.80	.70	.68	.56	.45
.95	.85	.70	.66	.55	.45
.92	.79	.66	.64	.54	.40

n = 35

[1]Station 42
[2]Station 40

Table D2. [illegible]

Distance from west edge of [illegible]					
400	100	80	[illegible]	0[1]	[illegible]
2.06	1.83	1.[illegible]8	1.81	1.94	1.81
2.01	1.78	1.[illegible]7	1.77	1.77	1.76
1.91	1.72	1.47	1.67	1.70	1.[illegible]
1.79	1.71	1.41	1.65	1.58	1.[illegible]
1.73	1.47	1.33	1.39	1.29	1.[illegible]
1.68	1.44	1.27	1.[illegible]1	1.24	1.[illegible]
1.59	1.34	1.20	1.29	1.24	1.[illegible]
1.50	1.32	1.11	1.2[illegible]	1.21	1.[illegible]
1.49	1.32	1.06	1.[illegible]4	1.14	0.[illegible]
1.48	1.30	1.05	1.16	1.08	[illegible]
1.40	1.27	1.02	1.16	1.02	.91
1.39	1.02	1.00	1.10	1.02	.88
1.36	1.00	0.96	1.02	1.02	[illegible]
1.33	0.94	.91	1.01	0.98	.81
1.28	.94	.88	1.01	.91	.81
1.27	.92	.83	0.92	.8[illegible]	.81
1.24	.85	.82	.89	.77	[illegible]
1.22	.85	.80	.87	.75	.80
1.18	.83	.80	.85	.74	[illegible]
1.16	.83	.77	.85	.74	.77
1.15	.81	.75	.80	.70	.76
1.09	.81	.70	.78	.68	.74
1.06	.81	.69	.78	.67	.74
1.05	.80	.67	.76	.65	[illegible]
1.05	.80	.66	.74	.64	.68
1.00	.79	.65	.72	.6[illegible]	.65
0.93	.78	.65	.70	[illegible]	[illegible]
.93	.78	.64	.70	.61	.62
.90	.74	.63	.69	61	.61
.89	.69	.62	.67	[illegible]	.60
.84	.69	.62	.66	[illegible]	.60
.83	.69	.62	.66	.[illegible]1	.58
.83	.6[illegible]	.60	.66	.[illegible]	[illegible]
.82	.67	.57	.65	.[illegible]4	.56
.82	.65	.55	.65	.[illegible]	[illegible]

n = 55

[1]Station 12
[2]Station 40

Table D3.--*Highest days of percolation from clear weather melt on south aspect for years 1970-73, in inches*

Distance from west edge of forest			
400	100	25	0[1]
1.91	1.97	1.73	2.31
1.86	1.68	1.51	1.64
1.78	1.46	1.37	1.55
1.70	1.34	1.35	1.50
1.44	1.17	1.31	1.28
1.43	1.12	1.20	1.24
1.41	1.06	1.14	1.17
1.41	1.05	1.07	1.15
1.41	1.01	0.98	1.06
1.23	0.98	.95	1.00
1.23	.97	.89	0.96
1.20	.87	.87	.92
1.16	.87	.86	.89
1.07	.85	.80	.88
1.06	.83	.78	.85
0.86	.83	.78	.81
.85	.81	.78	.77
.83	.79	.76	.77
.80	.76	.76	.75
.78	.74	.76	.73
.76	.73	.69	.73
.75	.73	.67	.71
.74	.73	.66	.70
.66	.72	.60	.67
.64	.70	.59	.62
.61	.66	.58	.61
.61	.62	.56	.55
.59	.62	.54	.55

n = 28

[1]Station 47

Table D4.--*Highest days of percolation from rain and snowmelt on south aspect for years 1970-73, in inches*

Distance from west edge of forest			
400	100	25	0[1]
2.21	2.43	2.02	2.41
2.21	2.26	1.88	2.10
2.15	1.89	1.84	2.09
1.84	1.61	1.48	1.97
1.75	1.61	1.43	1.80
1.73	1.57	1.42	1.76
1.64	1.44	1.40	1.69
1.43	1.33	1.37	1.58
1.40	1.05	1.29	1.40
1.30	1.02	1.15	1.34
1.25	0.95	1.05	1.26
1.24	.91	1.03	1.16
1.18	.86	0.99	1.10
1.15	.81	.94	1.04
1.10	.77	.84	0.97
1.08	.75	.82	.96
0.79	.72	.75	.93
.78	.68	.71	.92
.77	.68	.60	.90
.76	.63	.55	.86
.74	.62	.54	.84
.63	.57	.53	.84
.60	.57	.52	.84
.59	.55	.52	.81
.57	.55	.52	.78
.55	.54	.50	.74
.55	.52	.50	.73
.53	.52	.46	.72

n = 28

[illegible] n 1

APPENDIX E

Mean Daily Percolation Rates

in inches

Date	Distance from west edge of forest, in feet					
	1,000	400	100	50	25	0	0
			1969				
Nov. 1-Feb. 28		0.06	0.05	0.04	0.05	0.06	0.06
Mar. 1-31		.10	.08	.07	.09	.09	.09
April 30		.33	.27	.27	.26	.26	.27
May 7		.38	.32	.30	.29	.30	.29
8							bare
10		.44	.37	.34	.34	.34	
11		bare	.38	bare	bare	bare	
12			bare				
			1970				
Nov. 1-Feb. 28		0.04	0.03	0.03	0.03	0.05	0.04
Mar. 1-31		.03	.02	.03	.02	.02	.05
April 30		.11	.08	.07	.06	.05	.07
May 16		.29	.24	.22	.22	.18	.18
17							bare
18		.31	.26	.24	.23	.19	
19		.32	.27	.25	bare	bare	
20		.33	.27	bare			
21		bare	bare				
			1971				
Nov. 1-Feb. 28	[1]0.10	0.11	0.09	0.08	0.08	0.08	0.09
Mar. 1-31	.01	.02	.01	.02	.01	.02	.02
April 30	.19	.23	.17	.12	.19	.14	.15
May 2	.23	.28	.21	.15	.23	.16	.16
3							bare
5	.29	.33	.25	.18	.27	.20	
6	.31	.35	.26	.19	bare	.20	
7	.32	bare	.29	.21			
8	.31	bare	.29	.21			
9			.29	bare			
10			bare				
			1972				
Nov. 1-Feb. 28	0.06	0.09	0.07	0.05	0.06	0.12	0.06
Mar. 1-31	.23	.28	.31	.26	.28	.24	.26
April 30	.19	.24	.21	.17	.19	.17	.20
May 3	.21	.26	.22	.19	.21	.18	.21
4							bare
7	.26	.30	.25	.21	.23	.21	
8						bare	
10	.27	.32	.27	.23	.25		
11					bare		
12	.30	.34	.30	.25			
13	.31	bare	.30	.25			
14	bare		bare	bare			
			1973				
Nov. 1-Feb. 28	[2]0.07	0.07	0.05	0.06	0.05	0.06	0.06
Mar. 1-31	.14	.07	.07	.09	.03	.05	.06
April 21	.17	.12	.12	.13	.11	.10	.06
22							bare
23	.18	.13	.13	.14	.13	.11	
24						bare	
26	.19	.15	.15	.16	.14		
27					bare		
May 1	.21	.18	.18	.18			
2				bare			
5	.25	.23	.21				
6		bare	bare				
11	.25						
12	bare						

[1]Station 42
[2]Station 43

Table 1. [illegible]

[illegible] from west

Date	1,0[illegible]	[illegible]	100	25		
			1[illegible]			
Nov. 1-Feb. 28		[illegible]	0.06	0.04		
Mar. 1-31		.25	.22	.10		
April 10		.[illegible]	[illegible]	.16	.12	
13		[illegible]	.28	.17		
14		bare				
29			.31	.18	[illegible]	
30			bare			
May 4				.27	[illegible]	
5				bare	.24	
6					[illegible]	
			1971			
Nov. 1-Feb. [illegible]	0.11	0.10	0.11	[illegible]	[illegible]	[illegible]
Mar. 1-31	.10	.[illegible]	[illegible]	.07	.05	.05
April 10	.31	.[illegible]	.25	.20	.19	.13
13	.30	.[illegible]	.25	.21	.20	[illegible]
14	bare		bare			
20		.37		.25	.25	.14
21		bare				
24				[illegible]	.26	[illegible]
25					bare	
26				.30		.17
27				[illegible]		
May 4						.24
[illegible]						bare
			1972[illegible]			
Nov. 1-Feb. [illegible]	.09	[illegible]	[illegible]	.08	.10	.09
Mar. 1-31	.37	.41	[illegible]	.30	[illegible]	.33
April 1	.37	.42	.36	.31	[illegible]	[illegible]
2	bare	.41	bare	.31	.39	[illegible]
[illegible]		bare				
25				.30	.31	.25
26				.29	[illegible]	
27				bare		
May 4						.27
5						[illegible]
			1973			
Nov. 1-Feb. 29	.08	[illegible]	.07	.05	.09	.10
Mar. 1-31	.20	.19	.19	.11	.13	.09
April 3	.23	[illegible]	[illegible]	[illegible]	.16	
4	bare		.24	[illegible]	.18	.11
[illegible]			[illegible]			
6		.27		.16	.17	.11
[illegible]		.27		.17	bare	.11
8		bare				
9				[illegible]		.12
10				bare		
11						.14
12						bare

[1]Station 47

[illegible]Station 47.7

[illegible] Early rainfall and [illegible] [illegible] [illegible] rainfall and subsequent melt, particularly in clearings.

Haupt, Harold F.

1979. Local climatic and hydrologic consequences of creating openings in climax timber of north Idaho. USDA For. Serv. Res. Pap. INT-223, 13 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Climatic and hydrologic responses of small and large clearcuts on north and south aspects in northern Idaho were studied. Other attributes such as drip, snow interception, snowmelt, and rates of disappearance were evaluated with supportive data.

KEYWORDS: snowpack, snow accumulation, snowmelt, coniferous forests, forest hydrology, forest meteorology.

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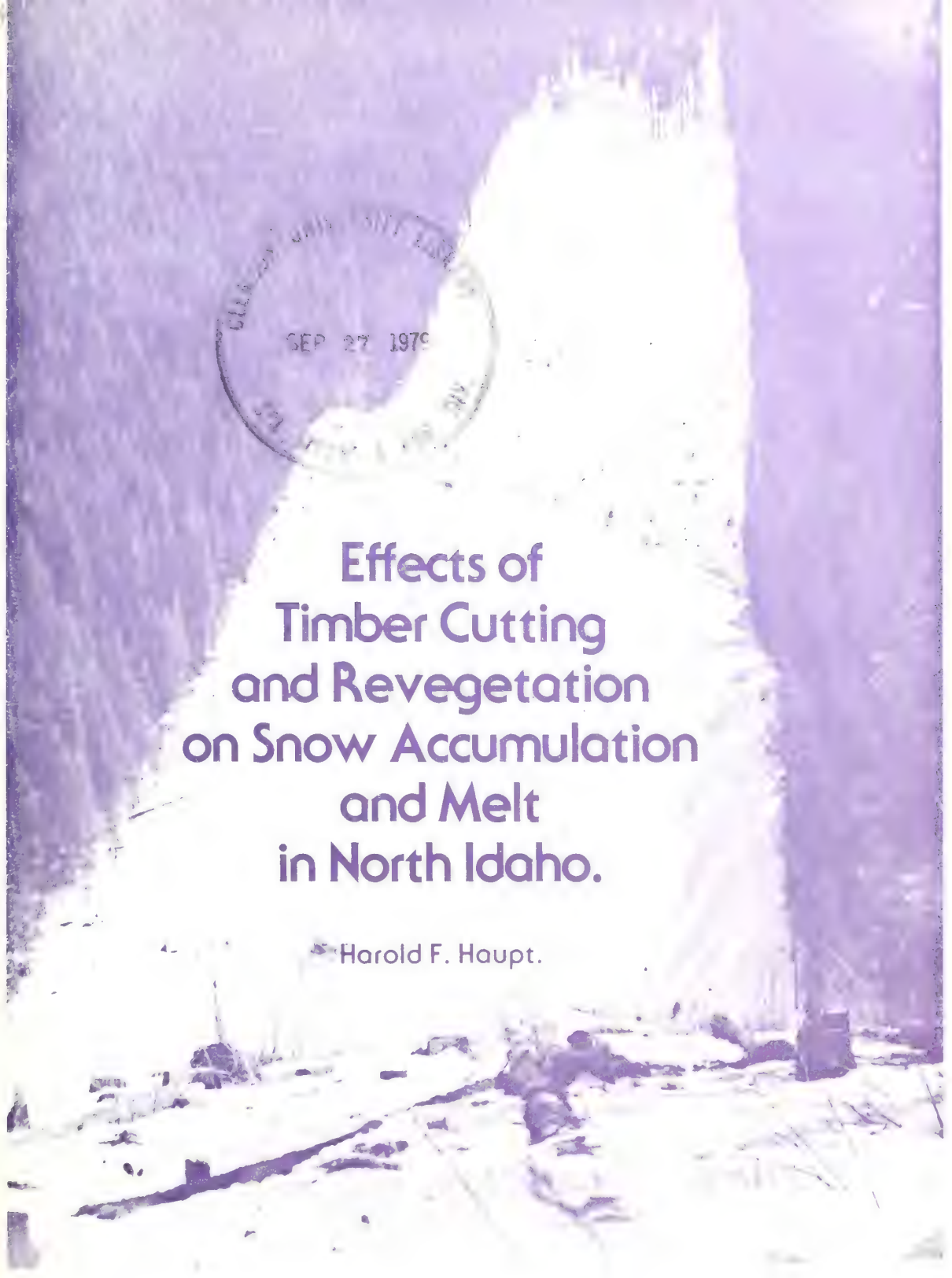

SEP 27 197

Effects of Timber Cutting and Revegetation on Snow Accumulation and Melt in North Idaho.

Harold F. Haupt.

USDA FOREST SERVICE RESEARCH PAPER INT-224
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE

THE AUTHOR

HAROLD F. HAUPT is the former leader of the Water Quality Management research work unit of the Intermountain Station at Moscow. He holds a B.S. degree in forestry and M.S. degree in range ecology, both obtained at the University of Idaho. For the past 29 years, he has conducted research in the fields of snowmelt hydrology, logging-road erosion, soil stabilization, and water quality in Idaho, Montana, Nevada, and California.

RESEARCH SUMMARY

Clearcutting on north- and south-facing slopes in a young mature, mid-elevation stand of mixed conifers in north Idaho resulted in substantial snow storage gains. The initial gain of 56 percent decreased to 37 percent after 34 years on the north slope following reestablishment of a new stand and later thinning of the 26-year-old sapling stand. Most of the increase was associated with savings from interception loss. Spring snowmelt rates also decreased gradually on the north slope because of crown-cover density increases in the new stand and subsequent expansion of shade cast by the canopies. On the south slope initial gains in snow accumulation were less (37 percent) because of greater winter melt and the greater evaporation/sublimation associated with south-facing clearcuts. In the 34-year study period, the new stand reestablished slowly because of brush competition, resulting in little if any change in snow accumulation gains or melt rates.

Effects of Timber Cutting and Revegetation on Snow Accumulation and Melt in North Idaho.

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CONTENTS

	Page
INTRODUCTION	1
SILVICULTURAL HISTORY	2
PHYSICAL ENVIRONMENT	4
METHODS	4
PEAK SNOW ACCUMULATION	5
Harvesting Effect	5
Climatic and Vegetative-Recovery Trends	8
SPRING SNOWMELT RATE	12
North Slope	12
South Slope	12
SUMMARY AND CONCLUSIONS	13
PUBLICATIONS CITED	14

INTRODUCTION

The mixed-species conifer forests of north [illegible] estern Montana represent the highest major water-producing zone in the interior West. recipitation amounts are high, ranging from [illegible] ne-half accumulating in a snowpack from November through April. The removal of tree over by clearcutting in patches, strips, or blocks greatly accelerates the winter torage of snow and thus increases the amount of water available to streamflow.

Augmentation of water yield represents a desirable goal of timber harvest but must e carefully controlled to avoid adverse effects on water quality and channel stability. o accomplish this goal, Forest Service hydrologists emphasize water quality as timber ales are designed, stressing that harvesting in a given watershed must proceed gradually to prevent an imbalance in the streamflow regime. Additionally, when reentering partially logged watershed, the reduction of water yield with vegetative recovery must e evaluated before deciding on how much new timber will be harvested (USDA Forest ervice 1973). Hydrologists in this region presently have very little documented evidence on the rise and fall of water yield as a timber stand is cut and subsequently evegetated.

Increases in water yield are generally proportional to the reduction in forest anopy, as well as to the intensity of partial cutting or percentage of clearcut area Stone 1973). The duration of the yield increase depends on how rapidly roots reoccupy he soil and how quickly the canopy is reestablished. Canopy reestablishment directly ffects snow accumulation.

Generally, research shows that gains in snow accumulation can be expected to persist onger than gains in soil water (Anderson 1969). Increased snow accumulation in lodgepole pine in the central Rocky Mountains will apparently persist for many decades and erhaps indefinitely (Gary, in press). In California, soil water [illegible] were negligible 16 to 20 years after clearcutting (Zeimer 1964).

In a recent study in north Idaho, soil water gains on a steep south-slope clearcut disappeared within 4 years after the climax understory brush reoccupied the area (Cline nd others 1977). In the same study, soil water increases were present for at least 5 years on a north-slope clearcut because herbaceous plants reinvaded and dominated the clearcut early in the recovery period, although the deeper-rooted brush was making rapid nroads by the fifth year. By extrapolation of the data, it would appear that the north-slope soil water gains would approach zero earlier than the 16 to 20 years observed n the California study. In contrast, on both the north and south clearcuts no downward rend in snow accumulation gains was evident 5 years after harvest (Cline and others 977).

This paper reports changes in snow accumulation gains on another site clearcut 54 years ago in the same general area. [illegible] clearcut and an adjacent stand of mature timber. Records were obtained periodically beginning with the second year and ending with the 31th year after harvest.

SILVICULTURAL HISTORY

The study site was located in the Benton Creek drainage of the Priest River Experimental Forest (PREF). In 1940 a strip clearcut, 330 ft (101 m) wide was extended from the ridge on the south side of Benton Creek and up the opposite slope to the ridge on the north side of Benton Creek (fig. 1 & 2). The clearcut was harvested with a conventional "jammer" cable system; slash from the cutting operation was hand piled and burned.

Original timber on the north slope consisted of young mature western redcedar (*Thuja plicata* Donn), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western white pine (*Pinus monticola* Dougl.), grand fir (*Abies grandis* [Dougl.] Forbes), and western larch (*Larix occidentalis* Nutt.). The south slope was stocked with young mature timber of three species--ponderosa pine (*Pinus ponderosa* Laws.), Douglas-fir (*Psuedotsuga menziesii* var. *glauca* [Beissn.] Franco), and western white pine.

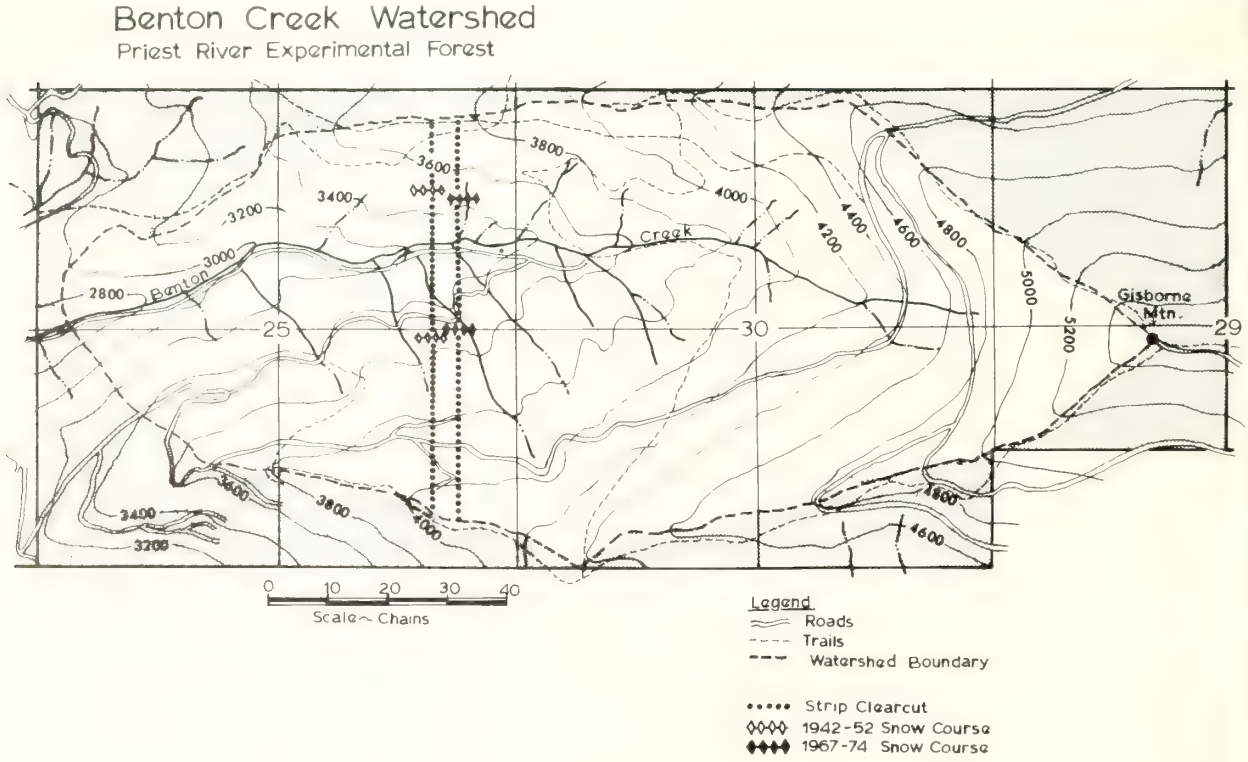

Figure 1.--Benton Creek watershed, Priest River Experimental Forest.

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[1]Graham, R. T. 1976. Silvicultural prescription, stand 20-1-24, Priest River Experimental Forest, Idaho Panhandle National Forests. Unpubl. rep., on file at Forestry Sciences Lab., Intermt. For. and Range Exp. Stn., Moscow, Idaho.

Natural reproduction on the north-slope strip clearcut, hereafter referred to as the "vegetative recovery plot," was well established [illegible]. A subsequent count later showed 5,520 stems per acre, consisting of 64 percent western white pine and 36 percent western hemlock. Heights of most saplings ranged from 10 ft (3 m) to over 15 ft (4.6 m). The south face quickly brushed over and as a consequence, the present stand is poorly to fairly well stocked with stems of the three original species (fig. 3).

A.

Figure 2.--Telephoto view of strip clearcuts, March-April 1949. A. North-facing slope. B. South-facing slope.

A 1967 thinning operation on the north slope showed grand fir, western redcedar, western larch, and western hemlock favored at 200, 400, and 800 trees per acre. The snow-sample study conducted on the vegetative recovery plot favored western redcedar at 400 trees per acre or an average spacing interval of 10x10 ft (3x3 m). The silvicultural prescription calls for thinnings in 1985, 2005, and 2025, with the final harvest in 2045.[1] No silvicultural treatment is planned for the south slope.

PHYSICAL ENVIRONMENT

The climate of the Experimental Forest is predominantly under the influence of the Pacific Ocean. Winter storms bring most of the annual precipitation in the form of snow. At the plot elevation (3,500 ft or 1,067 m), the estimated average annual precipitation was 33 to 36 in (84 to 91 cm). At this elevation, thaws are common throughout the winter; hence, the peak snow water equivalents measured from March 1 to April 1 underestimate the total winter snowfall.

Slope gradients on the north slope average 52 percent; on the opposite slope, 58 percent. For information on geomorphology and soils and complete data of the biological environment, the reader is referred to R. T. Graham's report.[1]

METHODS

In 1942 snow courses were established on the west half of the vegetative recovery plot and extended into an adjoining forest plot (fig 1). Snow depth and snow water equivalents (W.E.) were initially taken with a Mt. Rose snow tube and. later, with a federal-type snow sampler. Measurements began at approximately the time of maximum accumulation and continued about weekly through the melt period. This was repeated for 13 seasons on the north slope and 6 seasons on the south slope from 1942 through 1974.

The spacing and number of sample points and the location of snow courses changed during the study period as a result of amendments to the original study objectives (table 1). In 1967, the earlier courses were switched to the opposite side of the vegetative recovery plot (fig. 1). Because of expected differences in snow conditions between the east and west recovery-forest boundaries, measurements taken in the vicinity of the border zone were eliminated from the analyses. Data from the sample points for each year were averaged.

Table 1.--*Snow course stations (number and approximate spacing in feet)*

Year	North-face		South-face	
	Strip clearcut	Timber	Strip clearcut	Timber
1942	5-30	5-30	5-30	5-30
1949-52	9-20	6-20	8-20	7-20
1967-73	3-50	2-50		
1974	3-50	2-50	3-50	2-50

The structure of timber on the [illegible] the 34-year evaluation period. To test this assumption, a time-trend analysis was performed, including climatic data recorded at the PREF headquarters station (elevation 2,380 ft [725 m]). Data for the [illegible] determine if vegetation had recovered enough to have affected snow accumulation and melt. In other tests, water-equivalent changes in the snowpack over time were compared using regression techniques.

PEAK SNOW ACCUMULATION

Harvesting Effect

On the north slope, the removal of the young mature timber resulted in average snow W.E. gains in the vegetative recovery plot of 7.6 in (19.3 cm) for the period 1942 through 1952 (table 2). This was the period of early stand reestablishment and development (fig. 3). The average yearly gains compare favorably with those of 6.6 in (16.8 cm) measured in a narrower strip (200 ft [61 m]) cut in mature-overmature cedar-hemlock-white pine 1,000 ft (305 m) higher in elevation (Haupt, in press). Most of the snow accumulation increase was the result of snow caught in dense canopies that would have evaporated/sublimated had the trees not been harvested. Another portion of the increase was probably the result of wind eddy-forest edge effect during storms, and a fractional increase was perhaps due to slower winter release of water from the snowpack in the opening compared with the forest (Haupt 1972, in press). Gains on the recovery plot are shown in figure 4.

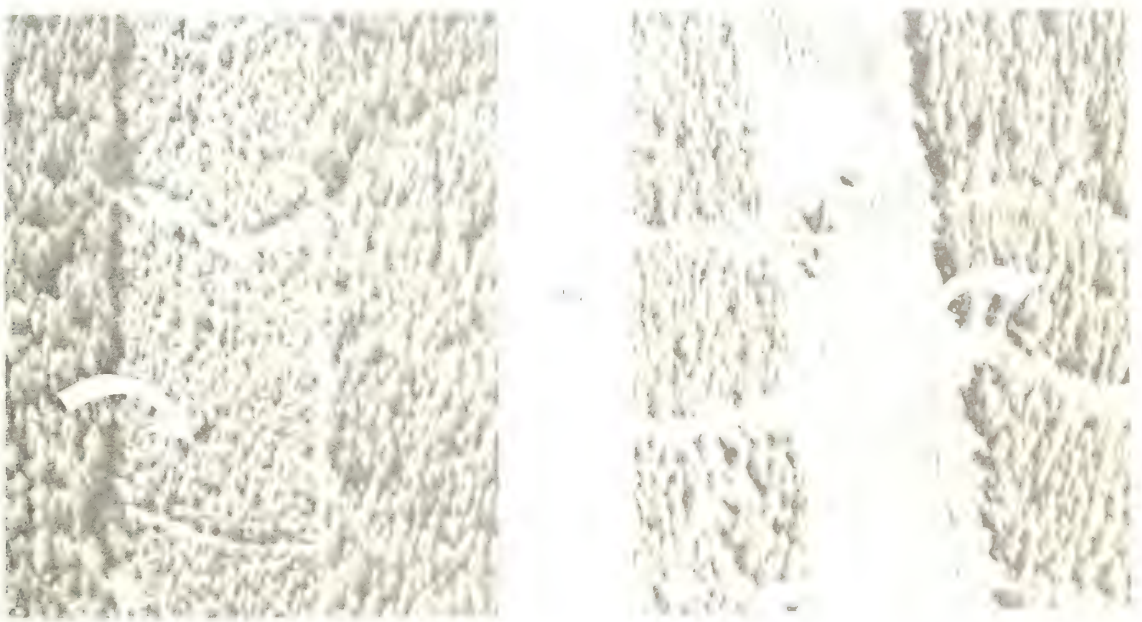


Figure 3.--Aerial view of strip clearcut [illegible]. A. North-facing slope before thinning. B. South-facing slope.

Table 2.--*Average peak snow water equivalents, gross melt, and average melt rate/day by plot condition-slope aspect-year*

Year	Peak snow accumulation				Spring snowmelt					
					Gross				Rate/day	
	Date	Forest plot	Recovery plot	Gains on recovery plot	Date of snow disappearance on forest plot (north slope) and recovery plot (south slope)	Forest plot	Recovery plot	Days until disappearance on forest plot	Forest plot	Recovery plot
		Inches				*Inches*			*Inches*	
					NORTH SLOPE					
1942	3/30	3.5	10.8	7.3	4/6	3.5	6.1	11	0.32	0.55
49	3/30	11.5	22.1	10.6	4/30	11.5	18.6	32	.36	.58
50	3/31	12.2	19.5	7.3	5/16	12.2	18.3	47	.26	.39
51	3/27	6.6	13.2	6.6	4/18	6.6	8.3	23	.29	.36
52	3/31	12.2	18.4	6.2	4/27	12.2	16.8	28	.44	.60
1967	4/4	4.4	13.0	8.6	5/9	4.4	5.1	36	.12	.14
68	3/19	1.4	7.8	6.4	3/28	1.4	0.1	10	.14	.01
69	3/28	14.6	17.7	3.1	5/3	14.6	11.8	37	.39	.32
70	3/26	11.2	15.5	4.3	5/7	11.2	10.0	43	.26	.23
71	4/12	6.4	12.5	6.1	5/2	6.4	8.3	21	.30	.40
72	4/3	2.0	7.4	5.4	4/29	2.0	1.9	27	.07	.07
73	3/19	1.1	5.2	4.1	4/2	1.1	0.5	15	.07	.03
74	4/2	9.0	14.0	5.0	4/30	9.0	9.0	29	.31	.31
					SOUTH SLOPE					
1942	3/4	4.4	5.8	1.4	3/20	3.6	5.8	17	.21	.34
49	3/1	7.9	10.9	3.0	4/6	7.0	10.9	37	.19	.29
50	3/10	8.0	11.9	4.0	4/19	6.9	11.9	41	.17	.29
51	3/15	3.6	6.3	2.7	4/4	3.3	6.3	21	.16	.30
52	3/10	8.8	12.6	3.8	4/12	7.1	12.6	34	.21	.37
1974	3/21	2.7	6.4	3.7	4/2	2.7	5.7	13	.21	.44

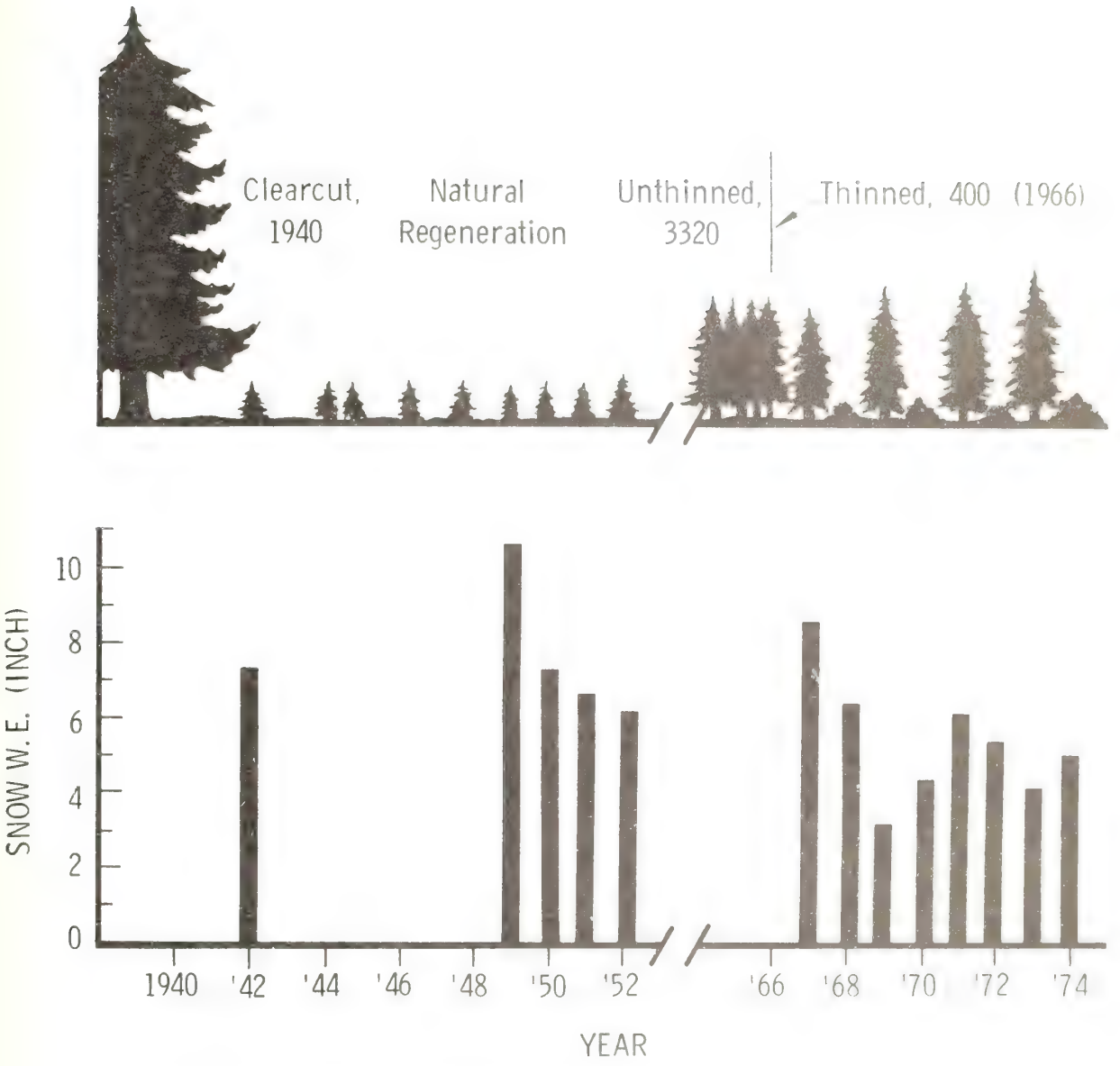


Figure 4.--Snow W.E. [illegible].

Water equivalent gains on the south slope recovery plot (fig. 3) averaged a yearly increase of 3.0 in (76 cm)--only 39 percent of that on the opposite slope (table 2). The measured gain in 1974 was slightly greater on the south-slope plot than the average for 1942 through 1952 (fig. 5). These plot gains are about twice those observed at a higher-elevation clearcut of similar size, shape, and slope, though with greater exposure to wind and energy input (Haupt, in press).

Physical processes are more severe on the south slope than on the north. However, a porous, less dense tree cover does allow more snowfall to filter through to the ground, and, in addition, sustained wind, often very gusty, tends to blow snow off the canopy and onto the ground below. As a consequence, less canopy-held snow is evaporated/sublimated.

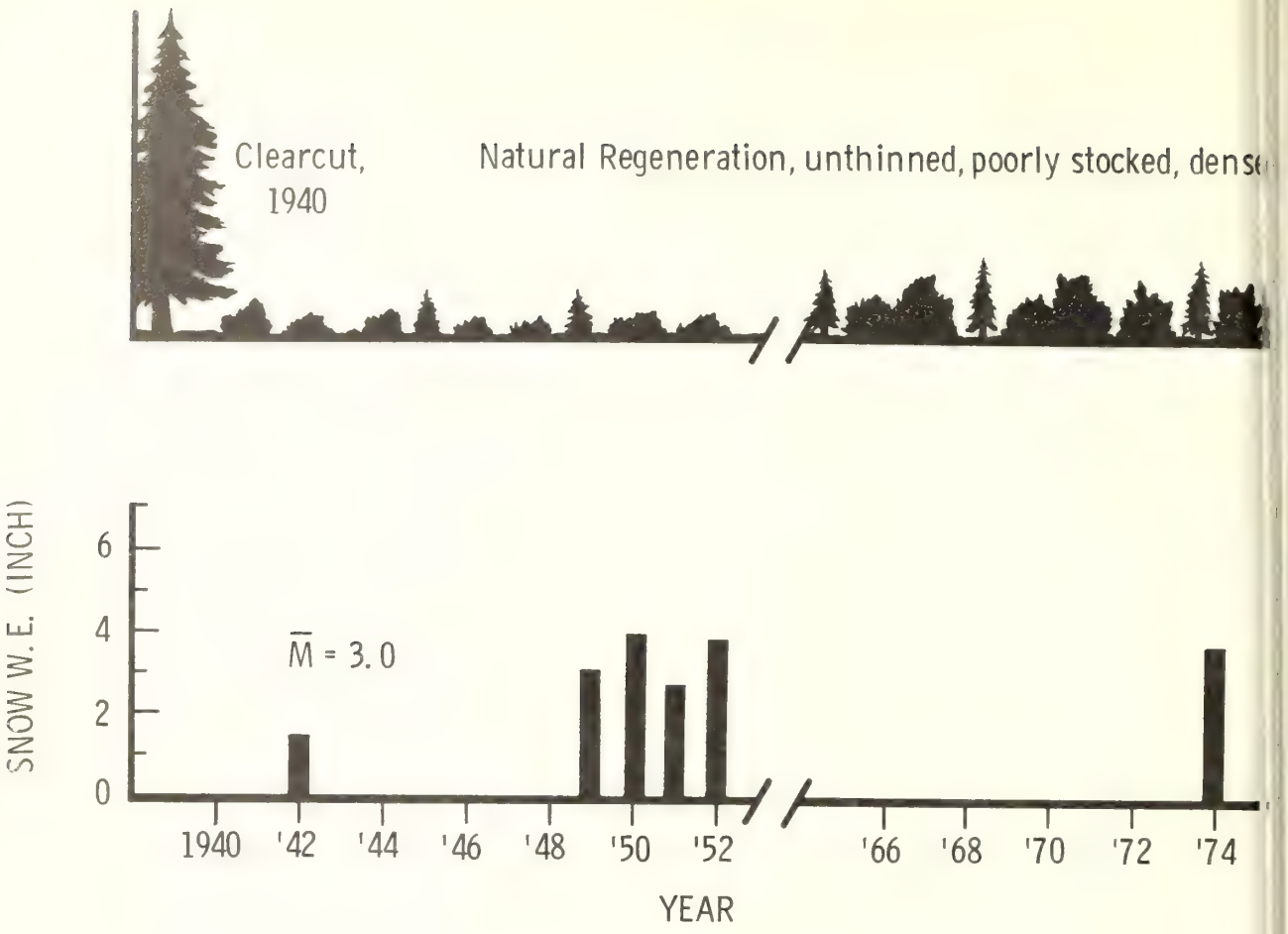


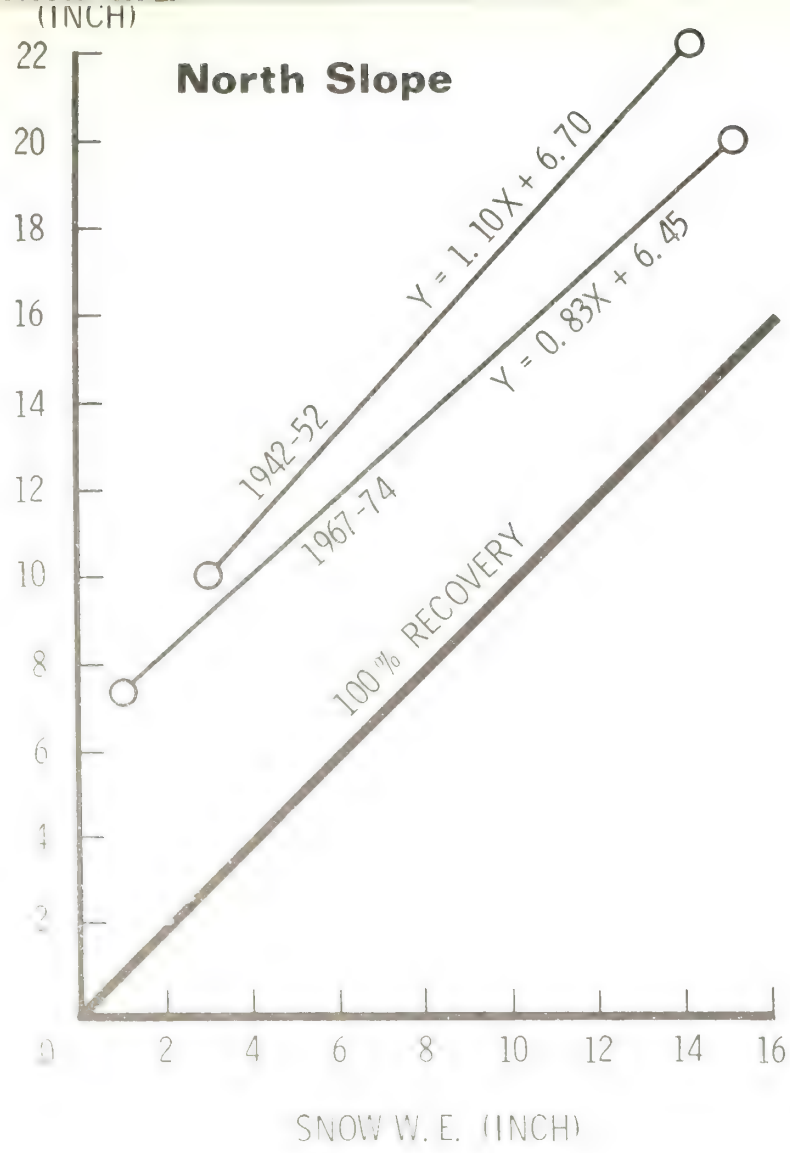
Figure 5.--Snow W.E. gains on recovery plot, south slope.

Once timber is cleared, the south slope opening presents an even more hostile environment for conserving snow. Subjected to considerable wind scouring, increased winter melting, and greater surface evaporation/sublimation, the clearing registers a smaller net increase in snow W.E. than a comparable opening on a north slope.

Climatic and Vegetative-Recovery Trends

On the north slope a greater depth of snow W.E. was measured in the recovery plot during the 1942 to 1952 period than in the interval from 1967 to 1974 (fig. 6). The levels or intercepts of the two regressions are significantly different ($P<=0.04$). This may be interpreted as a time-dependent decrease in snow W.E. gains. The curves lie well above the "100 percent recovery" line, a theoretical point in time when the structure of the timber on the recovery plot approximates that of the surrounding forest.

The apparent downward trend was tested by adjusting for year-to-year variations in winter precipitation and mean winter temperature (measured at headquarters station). Results of the test after including a time-trend variable are presented in table 3.


(INCH)
North Slope
22
20
18
16
14
12
10
8
6
4
2
0
Y = 1.10X + 6.70
Y = 0.83X + 6.45
1942-52
1967-74
100% RECOVERY
2
4
6
8
10
12
14
16
SNOW W. E. (INCH)

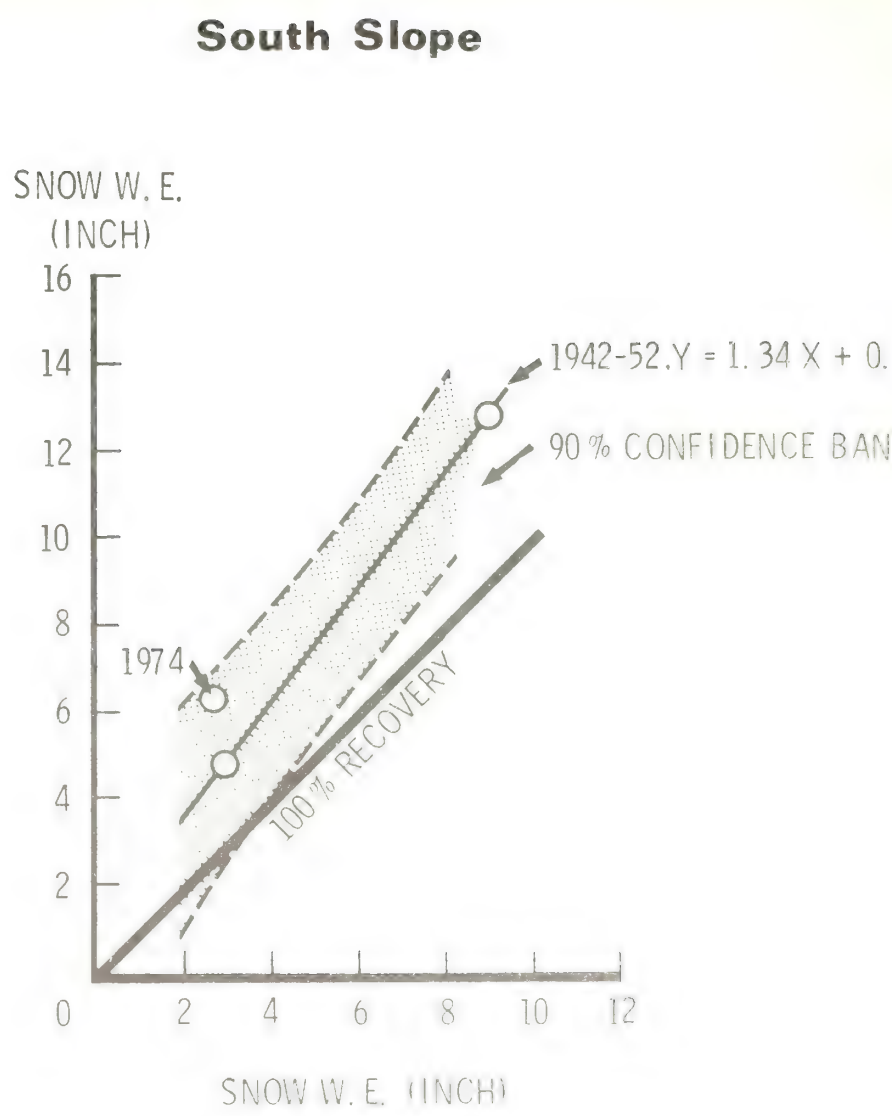

South Slope
SNOW W. E.
(INCH)
16
14
12
10
8
6
4
2
0
1942-52. Y = 1. 34 X + 0.
90 % CONFIDENCE BAN
1974
100% RECOVERY
2
4
6
8
10
12
SNOW W. E. (INCH)

Table 3.--*Time trend analyses by step-wise regression, north slope*

Snow characteristic/ plot	Variable	B value	R^2	F	Probability F
Peak snow accumulation					
Forest	Intercept	39.1890	0.534		
	Winter temperature[1]	-1.3382		6.20	0.03
	Winter precipitation[2]	0.3709		3.11	0.11
	Time trend[3]	-0.0405		0.16	0.70←rejecte
Recovery	Intercept	47.4722	0.717		
	Winter temperature	-1.3828		9.44	0.01
	Winter precipitation	0.4521		6.60	0.03
	Time trend	-0.1512		3.19	0.11
Spring snowmelt rate					
Forest	Intercept	-1.2085	0.654		
	Spring temperature[4]	0.0353		11.77	0.01
	Time trend	-0.0016		0.50	0.50←rejecte
Recovery	Intercept	-1.7558	0.874		
	Spring temperature	0.0527		25.27	0.001
	Time trend	-0.0078		11.68	0.01

[1]Mean daily temperature for 5 months, November through March.

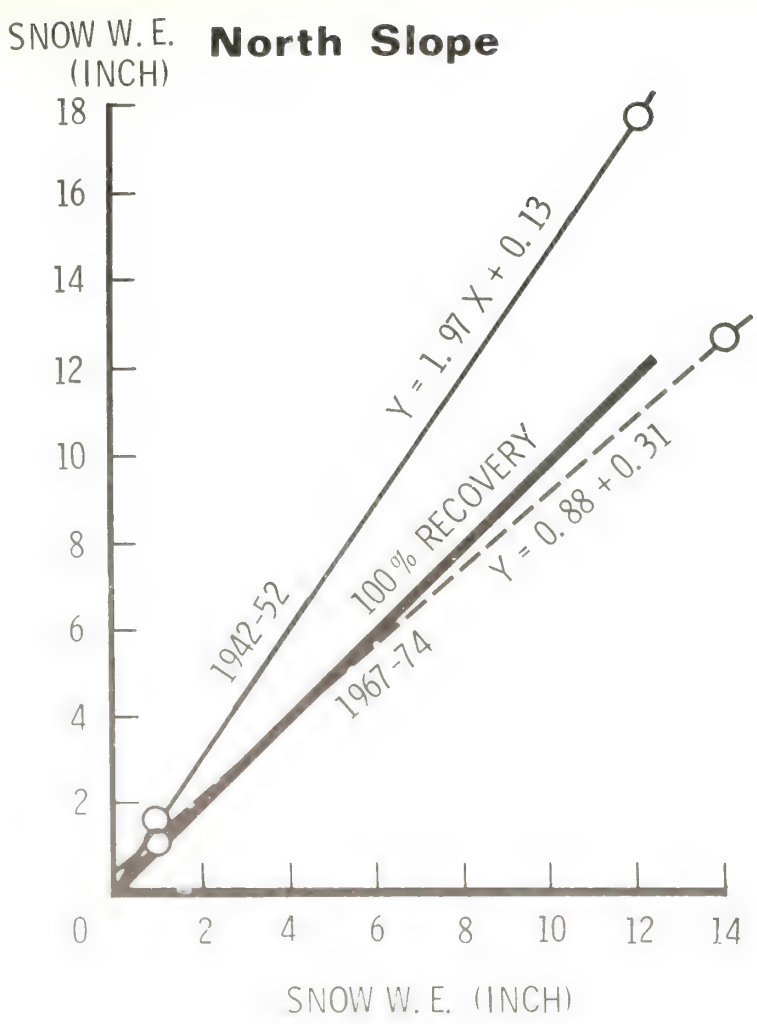
[2]Total precipitation for 5 months, November through March.

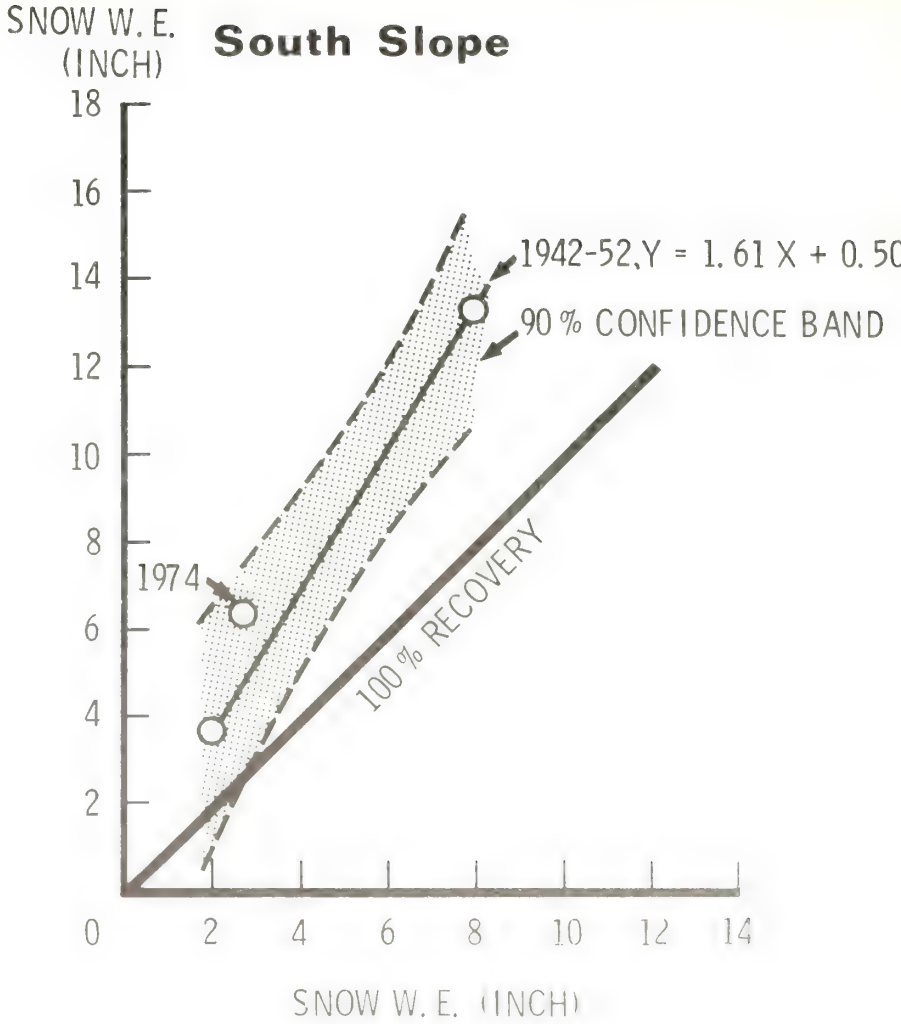
[3]Increasing numerical value with years since 1940 harvesting (i.e., 1941--1, 1974--34).

[4]Mean daily temperature for period beginning on day of peak snow accumulation and ending with day of snow disappearance on forest plot.

For the forest plot, the winter temperature coefficient was negative, indicating a reduction in peak W.E. associated with warm, thawing winters. The time-trend variable was unimportant, suggesting that change in the structure of the unmanaged forest from young mature to mature over 34 years of record had no detectable effect on peak snow accumulation.

On the recovery plot, the two climatic variables responded in the same manner (table 3). However, the negative time-trend coefficient was accepted as important ($P<=0.11$). Apparently the managed, sapling stand was effecting a gradual reduction in peak W.E. unexplained by winter temperature or precipitation input. The gradual decline resulted probably from increases in interception loss associated with the expanding canopies and slightly greater winter release of water from the snowpack. An earlier study conducted near the headquarters station revealed that individually weighed sapling trees (Douglas-fir and western white pine) will lose by evaporation to the atmosphere 4 to 5 percent of the total snowfall (Satterlund and Haupt 1970).


SNOW W. E. (INCH)
North Slope
18
16
14
12
10
8
6
4
2
0
2
4
6
8
10
12
14
Y = 1.97 X + 0.13
1942-52
100% RECOVERY
Y = 0.88 + 0.31
1967-74
SNOW W. E. (INCH)


SNOW W. E. (INCH)
South Slope
18
16
14
12
10
8
6
4
2
0
2
4
6
8
10
12
14
1942-52, Y = 1.61 X + 0.50
90% CONFIDENCE BAND
1974
100% RECOVERY
SNOW W. E. (INCH)

Under south-slope conditions, as shown in figure 6, the positive slope coefficien (>1.00) denotes greater differences between forest and recovery plots in winters with heavy snowfall.

Was there a trend on the south-slope recovery plot? The measurement taken in 197 lies within the 90 percent confidence band that was calculated based upon the variance about the individual value. Apparent lack of trend, if indeed this was the case, was not unexpected since the reestablishment of the new stand was progressing slowly. The were less than 100 trees per acre (<40 trees/ha) on the recovery plot.

SPRING SNOWMELT RATE

North Slope

Spring snowmelt rates were determined for the recovery plot by dividing the accum lated snowmelt--up to the time snow *disappeared* on the forest plot--by the number of days elapsed. For the forest plot, total snowmelt equaled the value shown for the pea W.E. Average rates by year are listed in table 2.

The regression curves (fig. 7) show much faster snowmelt on the recovery plot from 1942 to 1952 than from 1967 to 1974. The suggested downward trend was supported by results of the time-trend analyses (table 3). We expected the spring temperature coefficient to be positive and highly correlated with snowmelt. Again, the time-trend variable under forest conditions was unimportant. In the 34-year period, changes in melt rate were apparently associated only with deviations in spring temperature.

For the recovery plot, the analysis revealed a highly significant negative time-trend coefficient ($P<=0.01$). The occurrence of slight gradual decreases in snowmelt rate in recent years was entirely independent of temperature rise and fall. The thinn sapling stand--growing taller and enlarging its crown area each year--was apparently acting as a barrier to wind movement and was casting an ever-expanding shadow to shade the snowpack, thus effecting a gradual reduction in average melt rate.

Of special interest in figure 7, the 1967 to 1974 regression curve is plotted slightly *beneath* the 100-percent recovery line. After 34 years, the managed, sapling stand had recovered with melt rates equal to or slightly reduced from those associated with the residual mature timber. Crown-cover density in 1974 was estimated to be 0.22, compared with the mature forest figure of 0.80. Similar relations between crown-cover density and snowmelt on the north slope were reported by Packer (1971). The rate of snowmelt at his site *decreased* as crown-cover density *increased* from zero to 0.25, but then *increased* from 0.25 to 1.00. Experimentation conducted in the central Sierra Nevada with radiation instruments supports Packer's empirical results (U.S. Army Engineers 1956).

South Slope

Snowmelt rates were consistently greater in the recovery plot for the six measure ment periods (table 2). The lack of sampling data precludes clear evidence regarding trend. Because reductions in peak W.E. did not appear, we might not expect measurable change in melt rate. The lack of trend (not statistically tested) appears borne out b the 1974 data point, plotted within the 90 percent confidence band (fig. 7).

SUMMARY AND CONCLUSIONS

A study of the changes in snow accumulation and melt following timber harvest was conducted in a young mature-mature stand of cedar-hemlock-white pine in north Idaho. On the steep north slope, the immediate response to clearcutting was a 56 percent increase in peak snow W.E., most of which was associated with savings from interception loss. This pattern persisted until the new stand became established. After 26 years, a thinning of the untouched sapling stand reduced stems from 3,320 to 400 per acre (1,344 to 162 stems per hectare). Thirty-four years after clearcutting, a downward trend in peak snow W.E. was evident, although the overall increase remained a substantial 37 percent.

Based on the current trend, the gains will probably continue to diminish until the next thinning, scheduled for 1985. Reduction in crown-cover density at that time should reverse the trend and bring about a brief upswing in snow W.E. gain. The sequential pattern of decline followed by brief rise should be repeated, though in declining magnitude, at the time of commercial thinning in 2005 and again in 2045. By the end of the 100-year rotation, the managed stand should be accumulating more snow than an unmanaged stand of comparable age.

On the steep south slope, clearcutting resulted in a smaller peak snow W.E. increase of 37 percent. This average gain persisted after 34 years--even though the new stand was being slowly established. The silviculture plan called for no thinning, and unless the stand is thinned in the foreseeable future the gains will eventually decline.

Spring snowmelt rates were accelerated after clearcutting on the north and south slopes by 45 percent and 44 percent, respectively. After thinning the new north slope stand, melt rates declined over the years as crown-cover density increased the amount of shade. By the end of the evaluation period, melt rates were fully recovered and in fact were slightly less than those in the residual mature timber. Based on findings of other research we conclude that the minimum melt rate has been nearly reached in the sapling stand and will gradually *increase* as the crown-cover density approaches 1.00. The low melt rates provide the advantage of delayed snow disappearance, and should delay infiltration and subsurface flow to the stream channel at the time when bank-full volumes would be hazardous to channel stability.

On the south slope, the progress of stand reestablishment (unthinned) was proceeding slowly because of brush competition. Reduction of the high melt rate was not detected. Maintaining a pattern of accelerated melt rate is desirable in south slope clearcuts. First, it represents a practical hydrologic method for rushing melt water out of the system before high flows of other subdrainages in the watershed collect and contribute to the peak runoff. Second, the early disappearance of snow from south slope openings exposes browse forage sooner and at a time when most needed by big game.

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Clearcutting on north- and south-facing slopes in a young mature, mid-elevation stand of mixed conifers in north Idaho resulted in substantial snow storage gains.

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SALVAGING LOGGING RESIDUES IN MIXED-CONIFER STANDS OF NORTH IDAHO

A. L. CHASE

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RESEARCH SUMMARY

Two timber sales in north Idaho were experimentally relogged to determine if residues could be reduced through imposition of strict wood utilization standards. Relogging took place in 1975, one year following the initial logging. The 57-acre (23.1-ha) Danby Ridge sale, which had never been logged before, had an overstory of mixed sawtimber of medium stocking, 160 years old, and an understory of mixed polesize material of poor stocking, 80 years old. The 23-acre (9.3-ha) Lee Creek sale, which had been logged for cedar in the 1950's, had an overstory of mixed, 100-year-old sawtimber of medium stocking, with an understory of 60-year-old, poorly stocked, mixed polesize material.

The initial logging removed only green sawlogs 8 feet (2.44 m) long to a 10-inch (25.4-cm) top, or 10 feet (3.05 m) long to an 8-inch (20.32-cm) top, containing a minimum of 10 board feet (3 ft^3) and more than one-third sound. On Danby Ridge, about 15.7 thousand board feet per acre was harvested; about 6.7 thousand board feet per acre remained as dead and green residue; and about 0.1 thousand board feet per acre remained as residual timber. Volumes on Lee Creek were 9.8 thousand board feet harvested, 6.5 thousand board feet residue, and 2.5 thousand board feet residual timber.

On a 5-acre study plot, post-harvest residues 3 inches (7.62 cm) in diameter and larger amounted to 8,940 cubic feet (253 m^3) on Danby Ridge and 8,978 cubic feet (255 m^3) on Lee Creek. Relogging to recover material suitable for pulp, shake bolts, fence posts, and sawlogs with a 4-inch (10.16-cm) top, resulted in recovery of 5,291 cubic feet (150 m^3) on Danby Ridge, a residue reduction of 59 percent. An additional 3,931 cubic feet (113 m^3) was harvested on Lee Creek, a residue reduction of 44 percent.

On Danby Ridge, most of the salvage was suitable only for pulp, whereas on Lee Creek many pieces qualified for other products. Salvaged wood was skidded to the roadside but none was actually sold because the market for such materials softened as the study was nearing completion.

Production rates were measured for two harvesting machines common to north Idaho--a Caterpillar D2 tractor and a John Deere 540 rubber-tired skidder. On Danby Ridge, the tractor skidded 623 pieces (6,026 ft^3) (168.7 m^3) an average one-way distance of 70 feet (21.34 m) in 44 hours. On Lee Creek, the skidder moved 625 pieces (3,062 ft^3) (85.7 m^3) an average 204 feet (62.18 m) in 22 hours. Because of larger piece size on Danby Ridge, the two machines moved about the same volume of wood per hour.

The skidder operated at below payload capacity because residues were in small pieces. The tractor, although working close to capacity, was impeded by not having a winch. Until special harvesting equipment designed to handle residues is available, the small, multi-purpose skidder will remain the most practical machine for salvage logging.

CONTENTS

	Page
INTRODUCTION	1
THE STUDY AREAS	1
Selection of Study Areas	1
Study Area Descriptions	2
STUDY METHODS	4
Inventory Procedures	4
Relogging Production Procedures	4
CONVENTIONAL LOGGING	4
Utilization Standards and Products	4
Pre-Harvest Inventory	5
Post-Harvest Inventory	5
RELOGGING	7
Utilization Standards and Products	7
Pre-Relogging Inventory	7
Post-Relogging Inventory	9
Residue Reduction	10
Product Recovery	12
Production Analysis	12
DISCUSSION AND CONCLUSIONS	18

INTRODUCTION

The forester of today must increase the supply of wood fiber from [illegible] berland base while minimizing environmental damage, aesthetic disturbances, and fire hazards. One important method for accomplishing these objectives is to utilize more of the residue resulting from treatments of mature stands.

Although forest industries in the Northern Rockies are obtaining an increasing amount of raw wood from residues formerly abandoned or burned, volumes and characterists of this material and prospects for additional wood utlization are largely unknown in mixed conifer types of north Idaho. Little quantitative data is available on the efforts expended and results of adopting stringent utilization standards.

This report describes experimental relogging of two State of Idaho (Department of Lands) timber sales in the mixed-conifer type of north Idaho. The relogging was conducted in July and August of 1975. Both sales had been conventionally harvested within one year of the relogging. The study was intended to answer the following questions:

1. What are the volume and characteristics of logging residue after conventional logging?

2. What additional products and wood volumes could be removed in a relogging operation imposing stringent utilization standards?

3. What are the residue volumes and characteristics after relogging?

4. What relogging production rates might be expected using equipment common to north Idaho?

The study revealed that logging residues can be reduced approximately 40 to 60 percent in cubic volume, and significant quantities of useable raw wood can be recovered by imposing logging standards more stringent than normal. Relogging production rates were dependent on machine condition, capacity, and flexibility as well as site conditions and residue characteristics. Economic feasibility of relogging which depends upon the prevailing market for small logs and pulp bolts, was beyond the scope of this study.

THE STUDY AREAS

Selection of Study Areas

During the spring of 1975, six recently logged areas representing the mature, mixed-timber types of north Idaho were selected for preliminary residue measurments. A cutting block on each sale was transect-inventoried to determine residue character and volume. Comparison of timber sale statistics and transect survey results provided the basis for estimating amounts of wood harvested and residues. The range of stand conditions utilization standards, and residue amounts are presented in appendixes I and II to allow the interested reader to make generalizations concerning his own situation. The following criteria were used to select the study areas.

1. Utilization standards of sale and logging methods

2. Silvicultural treatment

3. Sale volume per acre

4. Age of timber cut and remaining timber

5. Species mixture on area

6. Availability of sale records

7. Degree to which residues represented post-logging conditions

Study Area Descriptions

The Danby Ridge sale near Rathdrum and the Lee Creek sale, east of Priest Lake, were selected for study on the basis of similarities and differences, as follows:

1. Similarities

   Terrain in both cases was gentle--10 to 15 percent.

   Only sawlogs were removed in the harvesting.

   Utilization standards were very similar.

   Both areas were harvested with small-to medium-sized mobile skidders.

   Access was excellent on both sales. Two or more sides were roaded.

   Sales records were good.

   Residue had been on the site for one year or less.

   The following stand descriptive criteria were in effect at the time of the conventional harvest. Sawtimber was 11.0 inches (27.94 cm) d.b.h. and larger; polesize was 5.0 to 10.99 inches (12.7 to 27.92 cm) d.b.h.; medium-stocked was 76 to 149 square feet (7.06 to 13.84 m^2) of net basal area per acre, or 40 to 70 percent by crown closure; poorly stocked was 20 to 57 square feet (1.86 to 5.30 m^2) of net basal area per acre, or 10 to 40 percent by crown closure.

2. Differences

   A seed tree cut of Danby Ridge removed 160-year-old stems and most of the volume (fig. 1). In contrast, a commercial thinning removed 100-year-old stems and about 80 percent of the volume of Lee Creek (fig. 2).

   The Danby Ridge sale, situated on a ridgetop exposed to frequent high winds and thunderstorms, had a high percentage of cull and broken-top trees (fig. 1). In fact, the seed tree cut actually turned out to be a clearcut, with scattered reproduction and 60- to 80-year-old poles. Lee Creek, located in a draw and bordered by a creek, was a healthy stand before and after harvesting.

   Danby Ridge had no history of past logging on the study site, although parts of the surrounding sale area had been previously harvested. Lee Creek had been cut for cedar products in the 1950's. Most of the dead, rotten pieces came from this operation.

   Prior to harvesting, the timber overstory on Danby Ridge consisted of mixed sawtimber, medium-stocked, 160 years old. The understory was mixed polesize material, poorly stocked, 80 years old. Overstory on Lee Creek was mixed sawtimber, medium-stocked, 100 years old. Understory vegetation was composed of mixed polesize material, poorly stocked, 60 years old.

Figure 1.--Danby Ridge sale after harvesting.

Figure 2.--Log landing at the Danby Ridge sale.

STUDY METHODS

Inventory Procedures

A 5-acre (2.02-ha) rectangular block on each of the two sites was laid out and all residue more than 8 feet (2.44 m) in length and 3 inches (7.62 cm) in diameter (small end) was measured. Original wood volume on the two study sites and the progressive effects of each treatment on residue amount and character were compared. Conventional logging was measured in board feet, relogging in cubic feet. Much of the residue remaining after logging was too small to be expressed in board feet. Only residue 3 inches (7.62 cm) or more in diameter was measured on the 5-acre (2.02-ha) study areas; residue smaller in diameter was deemed useless. A board foot: cubic foot ratio was computed for comparing the two measurements of volume.

Relogging Production Procedures

Two methods of skidding were compared on a round-trip basis. Miscellaneous production and nonproduction time was also analyzed. Skidding was timed with a stop watch and the turn pieces and volumes tallied.

CONVENTIONAL LOGGING

Utilization Standards and Products

Sawlogs.--Only green sawlogs (8 feet [2.44 m] long to a 10-inch [25.4-cm] top, or 10 feet [3.05 m] long to an 8-inch [20.32-cm] top) containing a minimum of 10 board feet (3 ft^3) and more than one-third sound were considered merchantable and were removed from both study areas. "One-third sound" meant that a piece containing a gross scale of 30 board feet must have 10 sound board feet to be merchantable. Rot, sweep, crook and checks were considered defects. Summation of cubic volume contained in residue pieces grossing 10 board feet revealed that an average 10-board-foot piece contained approximately 3 cubic feet.

Pulpwood.--Although no pulpwood was removed, Department of Lands pulp standards were hypothetically applied to determine how removal of this additional product would have affected residue volumes.

Pulpwood is defined as green or dead softwoods not merchantable for sawlogs but containing 10 board feet of pulpable material, and having one-third or more of the gross volume in sound wood.

Rot-infected wood is considered merchantable for pulpwood if the wood fibers cannot be extracted from the end of the log with the fingers. Logs having an unmerchant-

able core greater than the maximum allowable size listed in table 11 of A Manual of Instruction for Log Scaling and the Measurement of Timber Products (State of Idaho VO-ED No. 38) are not considered merchantable. Checks, splits, crook, and blue stain are not considered as defects in determining pulpwood volume.

Pre-Harvest Inventory

The pre-harvest inventory was found by adding green and dead pieces containing 10 or more gross board feet to the volume of the residual stand and scaled logs removed. Table 1 shows the pre-harvest volumes.

Table 1--*Preharvest volumes on north Idaho timber sales*

Sale name	Sale size	Volumes per acre				
		Removed	Residual[1]	Green Residue	Dead Residue	Total
	Acres					
Danby Ridge	57.0	15.7	0.1	2.8	3.9	22.5
Lee Creek	23.0	9.8	2.5	1.7	4.8	18.8

[1] Includes trees that blew down following logging.

Post-Harvest Inventory

Board foot and cubic residue volumes (pieces 8 feet [2.44 m] and longer and 3 inches [7.62 cm] and more in diameter) left after conventional logging are shown in table 2. Principle findings are:

1. Dead residue made up most of the gross volume on both study areas; however, green pieces were more abundant in both instances.

2. Rot was rather evenly spread between green and dead material on Danby Ridge regardless of piece volume. Large pieces, both dead and green, contained a high percentage of cull material on Lee Creek. Small pieces (less than 3 cubic feet) were generally defect free.

3. Useable (net) residue pieces on Danby Ridge were larger and less numerous than those on Lee Creek.

Because conventional methods of board-foot measure disregard pieces with end diameters less than 6 inches (15.24 cm), cubic volume provides a much better measure of total volumes than board-foot volume. However, a board foot:cubic foot ratio was desired to allow referral to the Pre-Harvest Inventory (table 1) and permit further categorization of the residue occurring on the two sites. Because this ratio is greatly influenced by piece size, a general ratio to cover the range of diameters was needed. On Lee Creek, dead residue (material dead before initial harvesting) was larger than

the green residue (created in the harvesting). Residue condition was then used to obtain board foot:cubic foot ratios for pieces containing 10 board feet (3 ft^3) or more, as follows: Lee Creek, dead residue, 5.78-1; green residue, 4.68-1; Danby Ridge, dead residue, 4.96-1; green residue, 5.01-1.

Table 2.--*Post harvest inventory (5 acres), number of pieces and gross volumes*

Item	Danby Ridge			Lee Creek		
	Pieces	*Ft^3*	*M bd.ft.*	*Pieces*	*Ft^3*	*M bd.ft.*
Dead residue	325	3,674	19.34	266	4,262	23.91
Green residue	377	2,996	13.65	591	2,482	8.53
Green blowdown	5	71	.41	85	838	4.04
Total	707	6,741 (190.74 m^3)	33.40	942	7,582 (214.57 m^3)	36.48
Pieces in total less than 1/3 sound	136	1,438	7.74	156	3,732	22.03
Pieces in total less than 3 ft^3	152	270	--	422	640	--
	Number of pieces and net (pulpwood base) volumes[1]					
Dead residue	208	2,472	12.70	122	941	5.80
Green residue	358	2,800	12.56	580	2,370	5.81
Green blowdown	5	31	.41	84	539	3.24
Total	571	5,303 (150.08 m^3)	25.67	786	3,850 (108.95 m^3)	14.85
Pieces in total less than 3 ft^3	136	236	--	399	607	--
Pieces in total less than 10 bd. ft.	152	--	--	399	--	--

[1]Includes pieces averaging 27% solid rot and 12% sound defect on Danby Ridge and 10% solid rot, 4.5% sound defect on Lee Creek.

RELOGGING

Utilization Standards and Products

Although utilization standards were more stringent than normal, an attempt was made to recover products merchantable at the time of the study and in the future. Discussion with those knowledgeable about buying and selling wood products led to the following products and standards.

Sawlogs.--Minimum length, 8 feet 6 inches (2.59 m); minimum top diameter inside bark, 4 inches (10.16 cm). All sawlogs cut in multiples of 8 feet (2.44 m). No sweep, splits, checks, or rot that would lessen the volume within these minimum dimensions. Specifications applied to coniferous species both green and dead.

Pulpbolts.--Minimum length, 8 feet (2.44 m); minimum top diameter inside bark, 3 inches (7.62 cm). In effect, one third or more sound and containing at least 0.4 cubic feet of useable wood fiber. All species, both hard and soft wood, green or dead, with the exception of western red cedar were considered for pulpwood. Pieces containing less than one-third sound wood by volume were not considered merchantable because they would likely disintegrate during handling. Large logs with crumbly rotten heartwood and solid shells were made into products using table 11 (VO-ED No. 38) as a guide.

Posts.--Lodgepole pine, western Larch, Douglas-fir, and western red cedar were considered merchantable for posts. Utilization standards were identical to sawlogs, except 7 feet (2.13 m) was the minimum length and 3 inches (7.62 cm) the diameter of the small end.

Shake and shingle bolts.-- Western red cedar was the only species considered for these products. All cedar more than one-third sound, at least 6 feet (1.83 m) long, at least 12 inches (30.48 cm) at the small end, and capable of squaring out sound 4-inch (10.16 cm) pieces was considered.

Pre-Relogging Inventory

As mentioned in the post-harvest inventory section, all residue was measured and counted. To evaluate the volume, utilization potential, and characteristics of the residue, the following information was recorded:

1. Type of residue--green (created in logging) or dead
2. Diameter at large end and small end, plus length to obtain volume; the formula for a uniformly tapered cylinder and a constant of 0.001818 was used to determine cubic foot volumes
3. Species of piece
4. Percentage of rot and sound defects that would lessen potential product recovery
5. Number of sawlogs, poles, posts, pulp bolts or cedar products that might be recovered.

All pieces to be skidded were marked with paint. At Danby Ridge, pieces that were likely to break up in recovery (less than one-third sound) were marked with a separate color and separated on the landing. Pieces likely to fall apart in relogging were not marked or skidded on Lee Creek. More will be mentioned about these pieces later.

The number of potential products made on site from useable pieces are shown in table 3. The table reveals that few products were made from pieces containing less than 10 board feet (3 ft^3) on Danby Ridge; this was not the case on Lee Creek. Green residue provided the source for most of the sawlogs on both areas. About 18 percent of the sawlogs on Danby Ridge were obtained from green blowdown material, resulting after the harvesting was completed. Forty-seven percent of the relogging sawlogs were obtained in this manner on Lee Creek. Pulpwood constituted the majority of relogging products in both cases, although the size of the material varied greatly between sites. Sixteen percent of the pulpbolts were made from pieces containing less than 3 cubic feet on Danby Ridge, while this material made up 47 percent of the pulp at Lee Creek. About 1.7 products were made from each piece of merchantable residue on Danby Ridge and 2.3 products on Lee Creek.

Table 3.--*Pre-relogging inventory (5 acres), potential products marked on site*

Product	Danby Ridge	Lee Creek
	No. of products	No. of products
Sawlogs:[1]		
Dead	5	42
Green	55	147
Green blowdown	12	132
Pulpbolts:[1]		
Dead	410	271
Green	513	907
Green blowdown	5	194
Posts:[1]		
Dead	--	1
Green	--	69
Shakebolts:[1]		
Dead	--	29
Green	--	18
Total products	995	1,810
Total pieces	707	942
Total useable pieces	571	786
Products in total that were made from pieces less than 10 bd.ft. or 3 ft^3	152	688

[1] See specifications in relogging: Utilization Standards and Products.

Post-Relogging Inventory

After completion of the relogging, each area was inventoried to determine the cubic volume of all pieces 3 inches (7.62 cm) or more in diameter and 1 foot (0.3 m) or more in length. Table 4 shows the results of this inventory. Pieces longer than 8 feet (2.44 m) are included. This is due to one of three causes: too rotten to make products, missed in the relogging, broken and abandoned. As mentioned before, pieces less than one-third sound were considered too rotten to move and stay together. This hypothesis was tested on Danby Ridge. These pieces were marked with blue paint and the operator conducting the relogging was asked to attempt skidding them; 70 pieces out of 136 broke up in the skidding operation. On Lee Creek, 156 rotten, no product pieces were left in place because of the anticipated breakup.

Table 4.--*Post relogging inventory (5 acres) residue 3 inch diameter or larger*

Study phase	Danby Ridge		Lee Creek	
	Pieces	*Ft³*	*Pieces*	*Ft³*
Residue volumes and pieces before relogging:				
Longer than 8 ft	707	6,471	942	7,582
Shorter than 8 ft	1,110	2,199	1,434	1,396
Total	1,817	8,940 (253 m³)	2,376	8,978 (254 m³)
Residue volumes and pieces after relogging:				
Longer than 8 ft	136[1]	1,438	156	3,433
Longer then 8 ft but missed or broken	5	12	80	218
Shorter than 8 ft	1,110	2,199	1,434	1,396
Total	1,251	3,649 (103 m³)	1,670	5,047 (143 m³)
Percent reduction	31.2	59.2	29.7	43.8

[1]66 pieces (641 ft³) skidded and decked separately; 70 pieces left on site; see post-relogging inventory for details.

Residue Reduction

One of the objectives of the study was to evaluate additional residue reduction achieved by relogging. Post-harvest residues 3 inches (7.62 cm) in diameter or longer amounted to 8,940 cubic feet (253 m^3) on Danby Ridge and 8,978 cubic feet (255 m^3) on Lee Creek. Relogging resulted in removal of 5,291 cubic feet (150 m^3) on Danby Ridge, a reduction of 59 percent. An additional 3,931 cubic feet (113 m^3) was removed in relogging Lee Creek, a reduction of 44 percent. A per-acre approximation of the cubic volumes existing prior to each treatment is shown in table 5. Pre-harvest volumes were found by applying a board foot:cubic foot ratio of 5 to 1 to the total of table 1. Post-harvest and post-relogging volumes were obtained from table 4.

Residue conditions following relogging on both study areas are shown in figure 3 (Danby Ridge) and figure 4 (Lee Creek).

Table 5.--*Gross residue volumes per acre for major phases of study*

Study phase	Danby Ridge	Lee Creek
	Cubic feet	*Cubic feet*
Preharvest	4,500	3,760
Harvesting:		
Post harvest	1,788	1,805
Residual	20	500
Total	1,808 (51 m^3)	2,305 (65 m^3)
Relogging:		
Post relogging	730	1,009
Residual	20	500
Total	750 (22 m^3)	1,509 (43 m^3)

Figure 3.--Danby Ridge sale following relogging.

Figure 4.--Lee Creek sale following relogging.

Product Recovery

The decked material could not be sold when the pulp market weakened throughout the Northwest about the time the study was concluded. Total merchantable products and cubic volumes are based on roadside-decked pieces. The figures in table 6 were derived by subtracting the post-relogging inventory from the post-harvest inventory. This method was followed because (1) only cubic volumes were measured during the relogging, (2) not all pieces were measured, and (3) some rotten pieces were left on Danby Ridge, and others were skidded. On Lee Creek, a number of sound pieces were broken or missed and were deducted from the total number of products recovered.

Table 6.--Number of products recovered (5 acres), as marked and decked.

Product	Danby Ridge		Lee Creek	
	Marked	Decked	Marked	Decked
	Pieces			
Sawlogs	72	72	321	321
Pulpbolts	928	921	1,372	1,219
Posts	--	--	70	69
Shake and shingle bolts	--	--	47	47
Total	1,000	993	1,810	1,656

Production Analysis

A principal objective of this study was to compare relogging production rates, using equipment common to north Idaho. Both the logger and the landowner must have incentives to remove and utilize residues. One real incentive is removing enough additional wood to pay for the cost of relogging. Value cannot be estimated unless the time required to harvest products or wood fiber is known. Production rates are known for logging equipment in the major timber types of north Idaho. The operator usually compares his equipment to these norms; given volume, distance of skid, and other operating conditions, he establishes his own production rate and costs.

Relogging production rates are not known; thus a logger has no comparative data from which to establish his own production rate and cost. The following analysis (tables 7 and 8), although limited to two stands and two skidding systems, should provide a basis for comparison.

Table 7.--*Relogging production: [illegible]*

Item	Danby Ridge	Lee Creek
Number of pieces	307	471
Number of days	5	[illegible]
Number of pieces per day	61	[illegible]
Number of pieces per 8-hr day	104	[illegible]
Average length of piece.....feet..	17.0	23.1
Average small-end diameter.....inch..	8.5	[illegible]
Volume.....cubic feet..	3520	[illegible]
Volume per day.....cubic feet..	704	[illegible]
Volume per 8-hr day.....cubic feet..	1220	1095
Number of turns	127	76
Number of turns per day	25.4	38
Number of turns per 8-hr day	44	42
Production time per day.....hours..	5.8	6.6
Production time per 8-hr day.....hours..	6.6	7.2
Non-production time per day.....hours..	0.8	0.7
Non-production time per 8-hr day..hours..	1.4	0.8

Table 8.--*Relogging production: average times and distances by turn*

Parameter	Danby Ridge	Lee Creek
Production elements:		
Time out..(all times in minutes)..	0.9	[illegible]
Hook time	2.3	[illegible]
Bunch time	1.8	[illegible]
Time in	0.9	1.1
Unhook time	1.1	1.0
Landing time	0.9	1.0
Round-trip time	7.9	9.6
Misc. production time	1.1	0.6
Non-production elements:		
Personnel not working	0.4	1.1
Machine down time	1.5	0.1
One-way distance.....feet..	70	204
Number of pieces	2.4	6.2
Volume.....cubic feet..	27.7	[illegible]

Skidding methods and equipment.--Two conventional mobile skidding methods were compared: a crawler tractor (Danby Ridge) and a rubber-tired skidder (Lee Creek).

1. Crawler tractor (fig. 5). The crawler tractor evaluated was an old Caterpillar Model D2, a machine used for light-duty construction, forestry, and farming. Skidding was accomplished by placing two or three chokers over a drawbar pin. Usual skidding procedure was to drag one to three logs to the edge of the long axis of the area. Because the tractor lacked a blade, little bunching of the logs was possible. The operator was instructed to skid all sound pieces and to attempt to skid unsound pieces. Machine down time was common. A total of 9 full and partial days were required to complete the skidding of the 5-acre (2.02-ha) tract.

Figure 5.--Relogging Danby Ridge with small crawler tractor.

2. Rubber-tired skidder (fig. 6). A medium-sized, rubber-tired [illegible] selected to represent a type of machine commonly used in north Idaho [illegible] unit was a John Deere Model 540 equipped with a winch and fi[illegible] to [illegible] chokers. In practice, five to seven logs were skidded to one of three landings. (The blade of the skidder was used to deck the pieces 6 to 8 feet [illegible]. The operator was free to skid as he wished, provided that all [illegible] were removed. No machine down time other than fueling was n[illegible] the operator. Two full days and 1 partial day were required to skid the [illegible] (2.02-ha) area. In both instances, the wood recovered was not [illegible] logger.

Timed observations.--Two people observed production on each study area. One individual, positioned at the landing, recorded number of turns and pieces and measured length and diameter on all pieces. The second person followed the turn of logs from the woods to the landing. All elements of the operation were timed with a stop watch to the nearest hundreth of a minute. Elapsed time for each event was noted, then the watch was kept running. This method allowed for a slight error when compared to total operating time (about 2 to 3 percent short). Unusual delays in production were noted. Because the crew members were in frequent contact, number of pieces per turn, turn number, and gross time could be compared.

Figure 6.--Relogging Lee Creek with rubber-tired skidder.

Because the skidding systems were investigated under different stand and operating conditions, total skidding time was broken into minor elements to facilitate comparative analysis of the data. Production elements directly related to output per turn (skidding) were added to obtain round-trip time. Breaks in the round-trip time were classified as productive and nonproductive delays. Productive delays include items such as hang-ups, straightening out chokers, and moving stumps. Nonproductive delays include operator breaks, machine down time, and operator discussion with the study team. Because of scheduling problems and the demands of other work necessary to complete the study, only a portion of the actual production process was timed on each area. Lee Creek was timed 2 days out of the 3 production days. Danby Ridge was timed 5 days out of 9 days. In both instances, the operator kept track of total hours worked, total number of turns, and pieces when the study team was absent. The results of measured total production variables can be seen in table 7.

The most important production activity for which data was gathered was roundtrip skidding time composed of six elements:

1. Out-time. Time required to move the skidding unit from the landing to the general area where the logs are to be hooked. Out-time starts when the skidder leaves the landing and stops when the machine arrives at the hooking site.

2. Hook-time. Time required to get a choker around a log. Hook-time starts when the operator gets off the skidder. It ends as he returns to his machine.

3. Bunch-time. Time required for lateral movement of one or more logs prior to moving towards the landing with a turn. It also includes the time necessary to break pieces loose from their initial resting place and place them where they can be reassembled. Bunch-time started as the machine or winch started to apply pressure to the choked log. It ended when the piece was lined up to start for the landing.

4. In-time. Time required for the skidding unit to move individual pieces, and the turn towards the landing. In-time started when a piece was started towards the landing. It ended when the load was deposited on the landing and the machine stopped.

5. Unhook-time. The time required to unhook the turn and drag the chokers free. Unhook-time started when the operator stopped on the landing and ended when the chokers were in position for the trip out and the operator was back on his machine.

6. Landing-time. Includes all time on the landing other than out-time, in-time, or unhook-time. Landing-time started when one of these three activities ceased and stopped when they were resumed.

A summary of average production elements by turn is shown in table 8. These averages are delay free. The effect of delays may be found by adding miscellaneous down time, machine down time, and operator time out to round trip time.

Production findings.--Tables 7 and 8 prove the value of using equipment designed and built specifically for moving small pieces of wood. Neither the tractor nor the rubber-tired skidder operated as efficiently as stand condition, piece size, and time would indicate. This conclusion is based on the following observations:

1. Poor tractor maintenance contributed to short work days.

2. Lack of a winch required excessive bunching time.

3. The tractor was much slower than the skidder. The average one-way skid was only one-third as far, but required 75 percent of the time taken by the skidder. Difference in skidding distance on two areas of similar configuration and size was due to the rubber-tired skidder making only three decks and the tractor stringing out the turns along both long axes of the area.

4. Due to larger residue size and a shorter one-way skid on Danby Ridge, the tractor moved approximately the same cubic foot volume per hour as the rubber-tired skidder moved on Lee Creek.

5. The skidder was worked far below capacity. The operator was unable to add enough chokers to work his machine efficiently. The tractor worked at or near capacity much of the time.

6. Because of its size the skidder crushed and broke more material than the small tractor broke at Danby Ridge.

Regression analysis.--Regression equations of the form $Y = b_0+b_1X$ were calculated for each of the independent variables thought to influence some dependent production element. The t-statistic was used to test the hypothesis that a linear relationship exists between the two variables considered. All tests were done at the 95 percent confidence level. A linear relationship was shown to exist in many cases. Looking at the R^2 value makes production variation more meaningful. R^2 indicates the proportion of variation in Y explained by X. For example, an average of 40 percent of the variation in time out (table 9) is explained by distance. The results for other production elements are shown in table 9.

Table 9.--*Relationships between production elements*

Y	X	Danby Ridge				Lee Creek			
		b_0	b_1	R^2	t-test	b_0	b_1	R^2	t-test
Time out	dist.	0.38	0.007	0.38	*	0.63	0.005	0.42	*
Time in	dist.	.59	.005	.21	*	.33	.004	.1[illegible]	*
Time in	turn vol.	.65	.01	.14	*	.94	.005	.009	
Time in	no. logs	.88	.02	.001		.64	.07	.03	
Hook time	no. logs	1.22	.46	.14	*	1.58	.37	.17	*
Bunch time	no. logs	.08	.71	.33	*	.87	.03	.00[illegible]	
Unhook time	no. logs	.50	.27	.13	*	.54	.07	.07	*
RT time	no. logs	5.64	.99	.08	*	5.87	.60	.16	*
RT time	turn vol.	7.34	.03	.02	*	9.16	.015	.00[illegible]	

$Y = b_0+b_1X$

*Indicates that on the basis of the data, a linear relationship exists between the two variables (t-test done at the 95 percent level).

DISCUSSION AND CONCLUSIONS

The data presented indicate the volumes and characteristics of logging residue left in north Idaho's mixed conifer stands following sawlog removal. By conventional sawlog standards, little merchantable residue remained on either site after logging. However, the material that was left offered real, although varying possibilities for additional product recovery and residue reduction. The study produced the following conclusions:

1. Residues left on site after conventional sawlog harvesting vary in defect, condition class, and individual size (table 2).

2. Initial harvesting of other products may reduce the need for relogging. Removing pulpwood of conventional standards would have left few useable residues on Danby Ridge (table 3). Conventional removal of pulp on Lee Creek would have left numerous small pieces of potentially useable residue.

3. Stringent utilization standards resulted in 993 products (mostly pulpwood) and 5,291 net cubic feet of wood fiber being removed in relogging Danby Ridge (tables 4 and 6). Some 1,656 products and 3,821 net cubic feet were removed on Lee Creek.

4. A cubic foot volume comparison of post-sale residue and post-relogging residue larger than 3 inches (7.62 cm) in diameter showed a 59 percent reduction on one area and a 44 percent reduction on the other.

Although further study is needed to determine the most efficient equipment for relogging, the following factors strongly influence production rates:

1. As with conventional harvesting, machine capacity and design must be matched with wood size and character. The value of equipment that matches residue conditions is best shown by the total relogging effort on the study areas. The tractor on Danby Ridge required 44 hours to skid 632 pieces (6,026 ft^3 [171 m^3]) an average one-way distance of 70 feet (21.34 m). The rubber-tired skidder needed only 22 hours to skid 625 pieces (3,062 ft^3 [87 m^3]) an average one-way distance of 204 feet (62.18 m). However, due to the larger piece size on Danby Ridge, on a per-hour basis approximately the same cubic volume was skidded on both areas.

2. Machines designed for conventional harvesting operate far below volume capacity on relogging sites where numerous small pieces of wood fiber must be recovered.

3. Until equipment designed for relogging is readily available, cheap multipurpose equipment appears to offer the most practical means for relogging.

Table 10.--*Pre-cruise timber sale statistics*

Sale name	Area size	Avg. slope	Cruise volume	Scaled volume Removed	Silvicultural treatment	Logging method	Utilization standards: Minimum d.b.h.	Minimum log length	Min. top size	Cull in log
	Acres	*pct.*	*------M b.f. 32ds------*				*Inches*	*Feet*	*Inches*	*Pct.*
CHILCO Mixed sawtimber, poorly stocked, 75 yrs. over mixed polesize, well-stocked, 50 yrs.	9.6	20	16.4 No pulp incl.	8.0 Pulp not removed	Intermediate thinning	Chainsaw felling & small crawler tractor skidding (D-4)	4	8.25	5.5	60-2.5
LEE CREEK Mixed sawtimber, medium stocked, 100 yrs. over mixed polesize poorly stocked, 60 yrs.	25.0	15	10.0 No pulp incl.	9.8 Pulp not removed	Marked-to-cut selection (commercial thinning)	Chainsaw felling & small crawler tractor skidding (JD-450)	9	8.25 10.25 12.25	5.5	60-2
DANBY RIDGE Mixed sawtimber, medium stocked, 100 yrs., over mixed polesize poorly stocked, 50 yrs.	27.0	15	17.2 No pulp incl.	15.7 Pulp not removed	Marked-to-leave seed trees	Tree length, chain saw felling & medium rubber-tired skidder	11	8.25 10.2 12.25	5.5	60-2.5
N. FK. SHAFER CREEK Mixed sawtimber, well stocked, 140 yrs.	45.2	60	26.8 No pulp incl.	35.1 Incl. pulp removed of 7.9	Marked-to-leave seed trees	Chainsaw felling, hammer high lead	1	8.25 10.25 12.25 14.25	5.5	60-2
[illegible] Mixed sawtimber, well stocked, 100+ yrs., over mixed [illegible], poorly stocked.	21.0	2	21.7 Pulp incl.	19.2 Incl. pulp removed of 15.2	Clearcut with removal of pulp	Chainsaw felling, medium rubber tired & crawler tractor skidder	10	8.25 10.25 12.25	5.5	60-2
[illegible] Mixed sawtimber [illegible], 100 yrs., over mixed [illegible], well stocked, [illegible].	100+	5	5.0 Pulp incl.	5.7 Incl. pulp removed of 4.7	All-age forest [illegible], incl. [illegible]	Chainsaw felling, small crawler [illegible] & small rubber tired skidder	9	8.25 10.25 12.25	5.5	60-2.5

APPENDIX II

Table 11.--*Post-sale transect survey residue measurements results*

Sale name	Volume 3" dia. & larger			Weight 3" dia. & larger			Weight smaller than 3"			Pieces 3" dia. + any length			*Products					
	Total residue D & G	Green residue	Dead residue				Fine Fuels											
				Total	Rotten	Sound	Total	0-1"	1-3"	Total	Sound	Unsound	SL	HL	CP	P	PB	SSB
	Ft³/acre			*tons/acre*						*pieces/acre*			*No./acre*					
Chilco	472	359	113	5.44	1.44	4.00	6.44	2.63	3.81	355	154	201	70	0	0	11	89	0
Lee Creek	3848	2329	1519	43.92	12.47	31.45	10.75	3.40	7.35	736	318	418	72	0	0	21	263	8
Danby Ridge	2411	1384	1027	25.57	13.61	11.96	11.82	1.95	9.87	492	190	302	20	0	0	0	155	4
N. Fk. Silver Cr.	2027	742	1285	21.36	11.06	10.57	11.80	3.02	8.78	635	347	288	54	0	0	15	155	8
Indian Hunt	3142	1365	1777	31.82	22.28	9.54	8.31	2.90	5.41	480	292	188	17	0	0	37	61	9
Jack Pine Flats	1817	663	1154	18.63	12.16	6.47	6.84	2.48	4.36	516	244	257	20	0	0	34	106	2

**Products* - *Priority Classification*

SL, Sawlog - 8'6" x 4" top or larger, all coniferous species
HL, Houselog - 8' to 12' x 9" top and straight, DF, WL, LPP, WRC
CP, Corral Pole - 8' to 20' x 3" top, DF, WL, LPP, WRC
P, Post - 6½' to 10' x 3" top or larger, DF, WL, LPP, WRC
PB, Pulp Bolt - 8' x 3" top or larger, all species except WRC
SSB, Shingle and Shake Bolt - 6'+ x 12" top or larger - WRC

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979—677-019/9

Chase, Alfred L.
1979. Salvaging logging residues in mixed-conifer stands of north Idaho. USDA For. Serv. Res. Pap. INT-225, 20 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Describes the condition and volumes of residues following conventional logging of two mixed conifer stands in north Idaho. Presents production rates and additional products recovered in relogging to more stringent than normal utilization standards.

Relogging of conventionally harvested stands offers possibilities for additional product recovery and debris reduction. Comparison of volumes of residue larger than 3-inch-diameter before and after logging showed a 44 percent reduction on one site and a 59 percent reduction on the other.

KEYWORDS: logging residues, salvage logging, logging practices, wood utilization.

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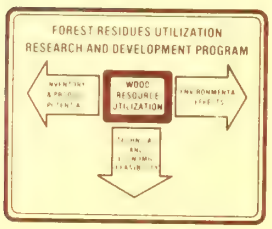
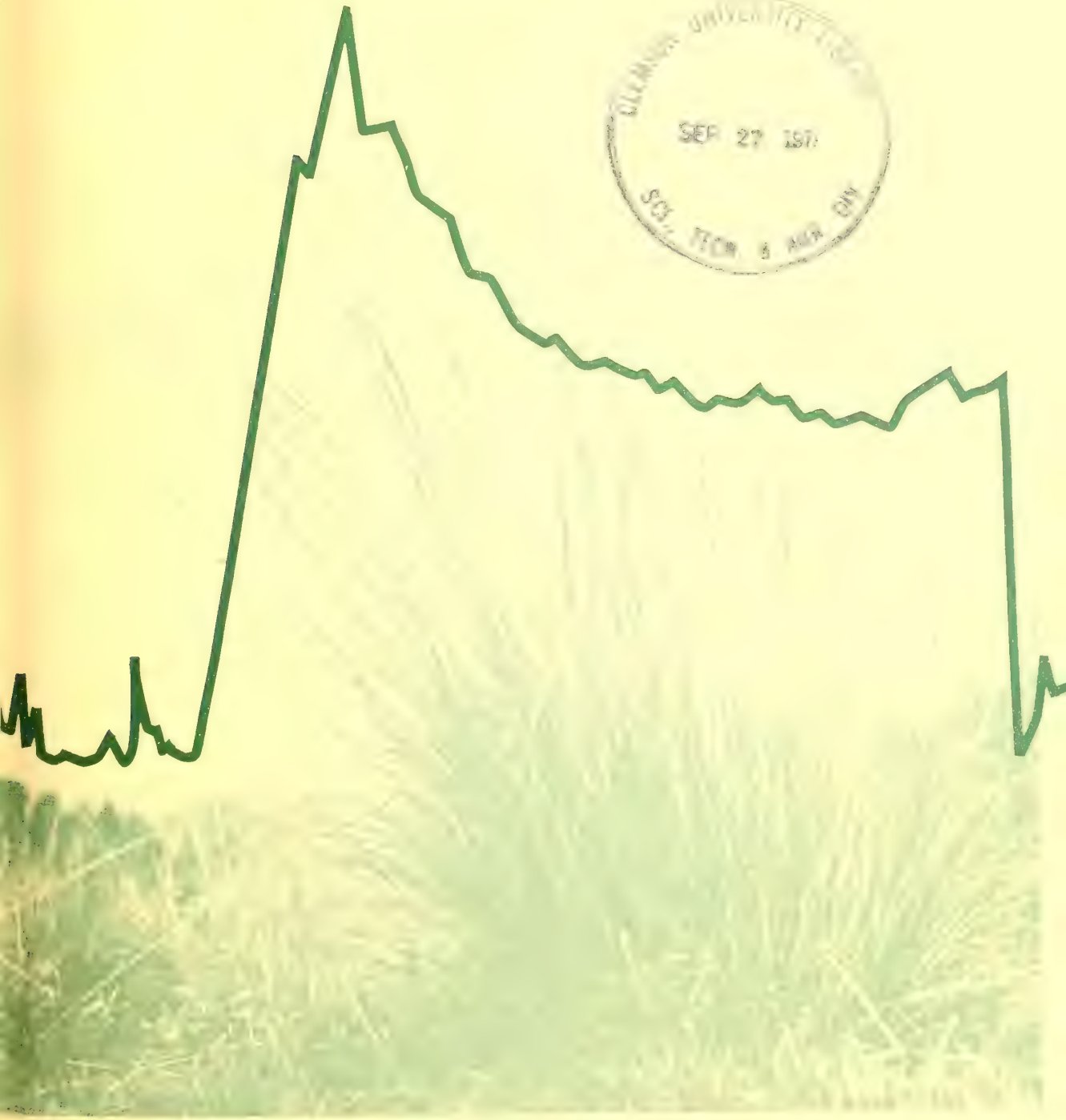


ESTIMATING LIVE FUEL MOISTURE FOR THE 1978 NATIONAL FIRE DANGER RATING SYSTEM

ROBERT E. BURGAN

SEP 27 19?
SCI. TECH. & AGR. DIV.



USDA Forest Service Research Paper INT-226
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Forest Service, U.S. Department of Agriculture

RESEARCH SUMMARY

A live fuel moisture model has been developed for the 1978 National Fire Danger Rating System (NFDRS) to provide more analytical and consistent moisture content estimates for herbs, shrubs, and grasses than was available with the 1972 NFDRS. This algorithm replaces the herbaceous vegetation transects used for the 1972 NFDRS.

Weather parameters are used to calculate moisture estimates for annual or perennial herbaceous plants and the leaves and twigs of small woody shrubs. The parameters are daily observations of maximum and minimum relative humidity, maximum and minimum temperature and hours of precipitation duration.

Because plants adapted to different environments respond differently to rainfall anomalies, the United States has been divided into four climate classes to provide a selection of drying rates by climate type (semiarid, subhumid, humid, wet). This permits adjusting seasonal moisture profiles for specific locations.

The amount or load of herbaceous vegetation is transferred between the live and the 1-hour time lag (dead) fuel category as a function of the live herbaceous plant moisture content. This capability utilizes improvements in the mathematical fire spread model that permits living vegetation to act as either a heat sink or a heat source, depending on whether these fuels are ignited in the fire front.

CONTENTS

Page

INTRODUCTION 1

LIVE FUEL MOISTURE ESTIMATION--1972 NFDRS 1

Woody Fuels 1
Herbaceous Fuels 2

THE LIVE FUEL MOISTURE MODELS--1978 NFDRS. 3

General Model Development 7
Herbaceous Fuel Moisture. 7
Woody Fuel Moisture Model 13

APPLICATION OF THE LIVE MOISTURE MODEL 15

PUBLICATIONS CITED 17

INTRODUCTION

The specific effect of living herbaceous plants and woody shrubs on fire behavior has been difficult to quantify (Deeming and others 1972). Intuitively we have known that live fuels intercept some of the radiant and convective energy from a fire, thereby interfering with the preheating of adjacent, unburned fuel elements. That is, the live fuels act as a heat sink. The result is a reduction in fire intensity and forward rate of fire spread.

If moisture content is high enough, living fuels will not burn, which in effect reduces the available fuel load. However, as the moisture content of the living fuels decreases, at some point these fuels can be desiccated and ignited within the flaming front, effectively increasing the available fuel load. The live fuels are then no longer a heat sink, but a heat source. Depending on the amount of live material, a rapid and often significant increase in fire intensity and spread can occur (fig. 1). Inclusion of these live fuel moisture effects improves the seasonal response of fire danger ratings.

Phenological processes define the general moisture profile of many plant species during a growing season. This general profile is modified by weather conditions to produce a specific seasonal moisture profile. Thus, particularly with respect to herbaceous fuels, the relative severity of drought can combine with phenological curing processes to produce a seasonal decrease in the live/dead ratio. From a fuels standpoint, curing of herbs and forbs affects the transfer of material from the living to the 1-hour timelag (1-h TL) class in addition to decreasing the moisture content of remaining live plants.

The 1972 National Fire Danger Rating System (NFDRS) (Deeming and others 1972) partially accounted for these effects by using subjective estimates for the condition of two classes of living fuels:

1. Leaves and small twigs of perennial woody shrubs

2. Herbaceous plants.

The following section briefly reviews how these estimates were made and some problems that resulted.

LIVE FUEL MOISTURE ESTIMATION — 1972 NFDRS

Woody Fuels

Only general levels of moisture in the twigs and foliage of living woody plants were considered in the 1972 NFDRS. The moisture levels varied according to three subjectively assigned growth stages, (Deeming and others 1972) but the loading of live woody fuels remained constant.

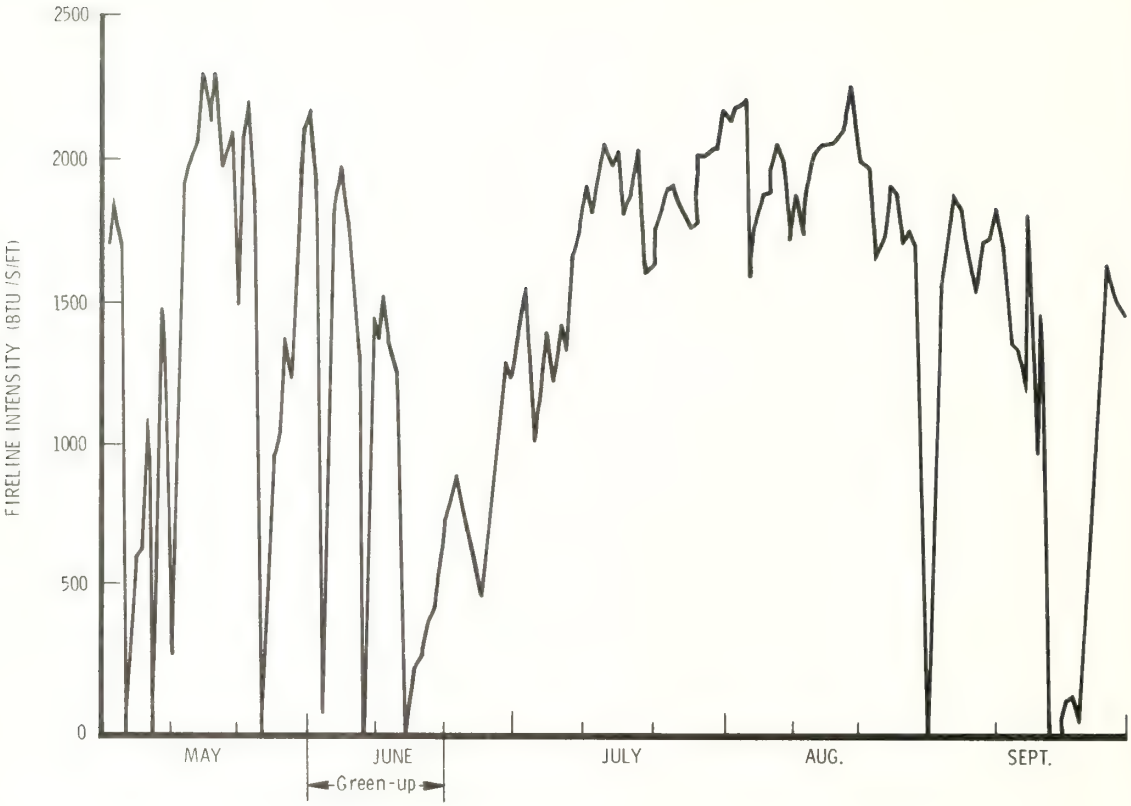

Figure 1.--This example for Libby, Montana, 1973, illustrates the fireline intensity for fuel model C with perennial grass (live/dead ratio 0.5). Intensity decreased markedly during the green-up period in the first three weeks of June, then increased again as the live herbaceous fuel moisture decreased during the summer.

Herbaceous Fuels

Living herbaceous fuels were assumed to have a constant moisture content in the 1972 NFDRS; however, the proportion of living herbaceous fuel varied. Range forage transects were used to estimate percentage of the fine fuels by volume that consisted of live herbaceous material. There were several disadvantages with this subjective procedure:

1. Transect location was critical. Microtopography produced significant differences in conditions between transects in close proximity.

2. Percent-green estimates made by different observers on a single transect were not consistent.

3. Important changes in the condition of herbaceous fuels were not necessarily observed or reported at appropriate times.

Fire danger ratings were particularly sensitive to percent-green estimates.

Although the 1972 NFDRS would respond reasonably well to properly reported changes in live fuel conditions, it had limitations.

1. Living fuels always acted as a heat sink, never a heat source.

2. A constant moisture content was assumed for the herbaceous fuels, but the live/dead ratio changed.

3. The quantity live of woody fuels was held constant, but the moisture content changed according to the growth stage assigned.

Thus, living woody fuels and herbaceous fuels were not treated similarly.

Improvements in the fire model used in the 1978 NFDRS made it possible to treat live fuels more realistically. The result was that live fuels could act as a heat sink or as a heat source. The live fuels became a heat source when their moisture content became so low that they could be desiccated and ignited during combustion of the dead fuels. However, if the moisture content was above some critical level, live fuels would not burn, but rather would act as a heat sink (Albini 1976).

The live fuel moisture model was developed to provide more analytical and consistent estimates of live fuel moisture at a time when capability to use this information had improved.

THE LIVE FUEL MOISTURE MODELS — 1978 NFDRS

The live fuel moisture model was developed to replace the herbaceous vegetation transects used in the 1972 NFDRS. Although it is not rigorously based on principles of plant physiology, the model does provide a broadscale approximation of the moisture content of living herbaceous plants, leaves, and twigs of small woody shrubs.

In the original live fuel model proposed by Rothermel,[1] plant moisture was determined as a function of the Keetch-Byram Drought Index. However, several empirical factors required to control plant response to drying and wetting could not be derived for all climates of the United States.

During development of the 1978 NFDRS, we noticed the 1000-hour timelag (1000-h TL) fuel moisture developed by Fosberg and others[2] responded to wetting and drying cycles similar to that expected for the live fuels. Thus, with some modifications, the 1000-h TL fuel moisture now serves as the basic meteorological filter for calculating live fuel moistures.

Plants adapted to different moisture regimes respond differently to rainfall anomalies. Those adapted to a moist environment will lose moisture faster during drought than those from a dry environment. An essential feature of the live fuel moisture model used in the 1978 NFDRS is a selection of drying rates by climate type or class.

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[1]Rothermel, Richard C. (n.d.) Live fuel moisture model. Manuscript in preparation. Northern Forest Fire Laboratory, Missoula, Mont.

[2]Fosberg, Michael A., Richard C. Rothermel, and Patricia L. Andrews. (n.d.) Moisture content calculations for the 100- and 1000-hour timelag fuels in fire danger rating. Manuscript in preparation. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

The United States can be divided into many climatic zones; but four climate classes were enough to provide the broadscale plant moisture responses needed for rating fire danger. These four climate classes were adapted from Thornthwaite's earliest climate classification system (Thornthwaite 1931). His arid and semiarid provinces were grouped into Climate Class 1 because the true desert is of little real concern to fire management. Also, in terms of fire behavior, the subhumid province groups better with the humid province than with the dry, subhumid province. The climate class descriptions, the general geographic areas to which they apply, and the vegetation characteristic to each, are provided in table 1. Figure 2 shows the general locations to which the climate classes apply.

Table 1.--*Climate class selection guide*[3]

NFDRS climate class	Thornthwaite[4] humidity province	Characteristic vegetation	Regions
1	Arid	Desert (sparse grass and scattered shrubs)	Sonoran deserts of west Texas, New Mexico, southwest Arizona, southern Nevada, and western Utah; and the Mojave Desert of California
	Semiarid	Steppe (short grass and shrubs)	The short grass prairies of the Great Plains; the sagebrush steppes and pinyon/juniper woodlands of Wyoming, Montana, Idaho, Colorado, Utah, Arizona, Washington, and Oregon; and the grass steppes of the central valley of California
2	Subhumid (rainfall deficient in summer)	Savanna (grasslands, dense brush and open conifer forests)	The Alaskan interior; the chaparral of Colorado, Arizona, New Mexico, the Sierra Nevada foothills, and southern California; oak woodlands of California; ponderosa pine woodlands of the West; and mountain valleys (or parks) of the Northern and Central Rockies
3	Subhumid (rainfall adequate in all seasons)	Savanna (grasslands and open hardwood forests)	Blue stem prairies and blue stem-oak-hickory savanna of Iowa, Missouri, and Illinois
	Humid	Forests	Almost the entire Eastern United States; and those higher elevations in the West that support dense forests
4	Wet	Rain forests (redwoods, and spruce-cedar-hemlock)	Coast of northern California, Oregon, Washington, and southeast Alaska

[3]Deeming and others 1977.
[4]Thornthwaite 1931.

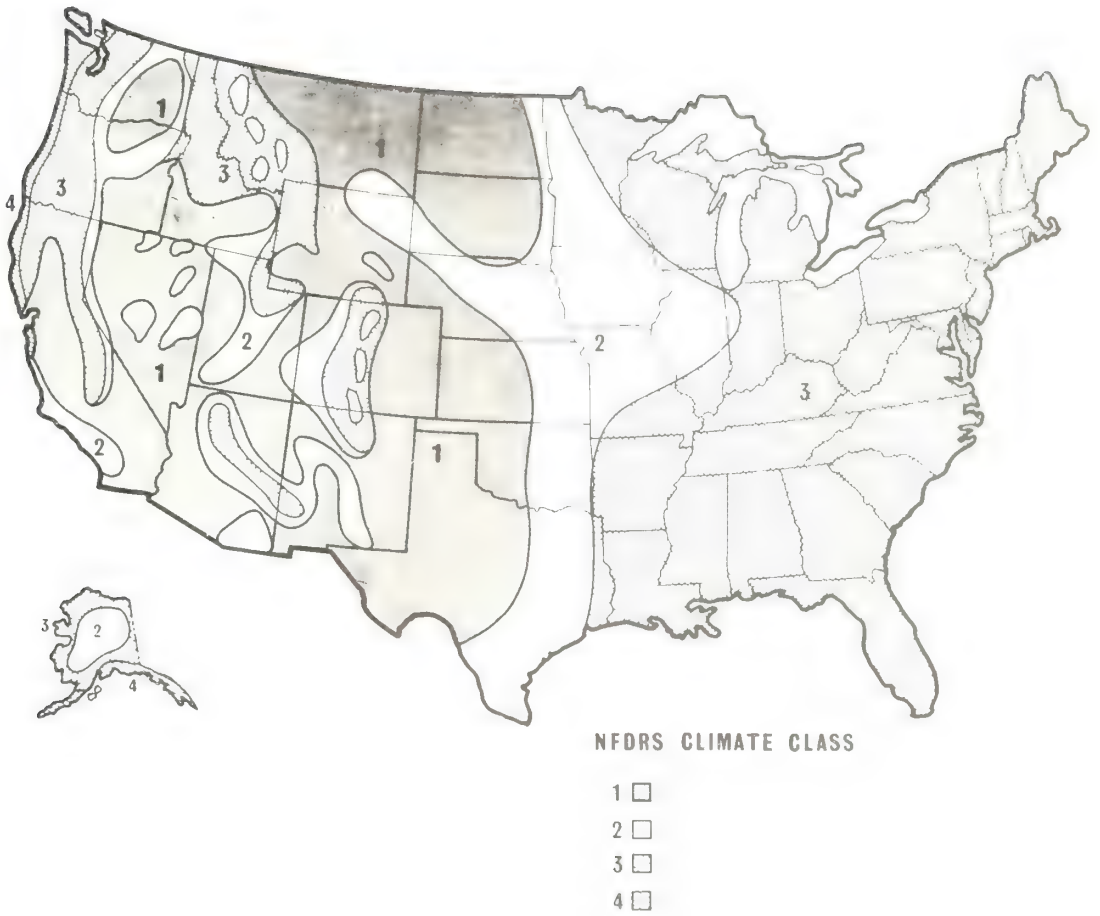


Figure 1.--Map of the [illegible] classes (Deeming and others 1977).

Different linear drying rates are defined by climate class for annuals, perennials, and woody plants. But within a particular climate class, a single drying rate is assumed for live woody plants throughout a growing season. For live herbaceous plants, drying occurs in two stages--green stage when the herbaceous moisture is above 120 percent, and transition stage for moistures between 120 percent and 30 percent. In the green stage, both annuals and perennials dry at the same rate. But in the transition stage, the drying rate is faster for annuals than for perennials.

To define the drying rates, the endpoints of the drying curves were required. Weather data from several locations within each climate class were used to plot seasonal 1000-h TL fuel moisture profiles. Then typical plant moistures for each climate class and vegetation type (woody, annual, perennial) were matched with these profiles. Because measurements of seasonal moisture variation in woody and herbaceous plants were not generally available from different parts of the United States, the live fuel model was calibrated to produce reasonable moisture values. Performance objectives are shown in table 2.

Table 2.--*Minimum moisture content for live fuels*

Type of season	Grasses and forbs		Shrubs, twigs, and foliage
	Annuals	Perennials	
	Percent		
Wet	∿30 (Late cure)	>80	>110
Normal	≤30 (Normal cure)	50-80	80-100
Dry	<30 (Early cure)	<50	50-80

The highest live fuel moistures were defined to be 250 percent for the herbaceous fuels and 200 percent for the live woody shrubs at a 25 percent 1000-h TL fuel moisture. At the lower end of the moisture scale, herbaceous plants were considered cured at 30 percent moisture content and woody plants dead or dormant if their moisture content dropped to 50 percent. The minimum woody and herbaceous moistures were matched with typical minimum 1000-h TL moistures and X1000 values, respectively, for each climate class. The slopes and intercepts of the drying curves for each climate class are provided in table 3.

The live fuel moisture algorithm gives the fuel models a dynamic character by simulating the curing of the herbaceous fuels. This is accomplished by transferring fuel load from the live herbaceous class to the 1-h TL class as herbaceous fuel moisture drops below 120 percent during the growing season.

Table 3.--*Slopes and intercepts for the drying rates of the live fuel models*

Climate Class	Woody Fuels		Herbaceous Fuels					
			Annuals and Perennials		Annuals		Perennials	
			Green Stage		Transition Stage		Transition Stage	
	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept
1	7.5	12.5	12.8	-70.0	18.4	-150.5	7.4	11.2
2	8.2	-5.0	14.0	-100.0	19.6	-187.7	8.3	-10.3
3	8.9	-22.5	15.5	-137.5	22.0	-245.2	9.8	-42.7
4	9.8	-45.0	17.4	-185.0	24.3	-305.2	12.2	-93.5

General Model Development

Rothermel[1] provided the empirical data used for development and initial testing of the live fuel moisture model. He used the xylene distillation technique of determining moisture content to construct profiles of herbaceous and woody plants near Missoula, Mont., during the 1975 and 1976 fire seasons. The live fuel model was initially developed to emulate these moisture profiles, then adjusted to produce reasonable moisture profiles for the remainder of the United States.

Herbaceous Fuel Moisture

Moisture Computations - The live herbaceous fuel moisture (HFM) is a function of a modified 1000-h TL fuel moisture called the X1000 value, which is a function of the daily change in the 1000-h TL fuel moisture. The original effort to relate herbaceous fuel moisture directly to the 1000-h TL fuel moisture proved reasonable during periods of drying, but it produced excessive herbaceous fuel moisture recovery during periods of precipitation. Therefore, the X1000 value was designed to decrease at the same rate as the 1000-h TL fuel moisture, but have a slower rate of increase.

During the growing season the X1000 value is calculated as:

$$X1000 = YX1000 + K_1K_2(\Delta MC1000)$$

where: YX1000 = yesterday's X1000 fuel moisture

K_1 = drying or wetting factor

K_2 = temperature factor

$\Delta MC1000$ = 24 hour change in the 1000-h TL fuel moisture

If $\Delta MC1000 < 0$ (drying) $K_1 = 1$

If $\Delta MC1000 \geq 0$ (wetting) $K_1 = 0.0333X + 0.1675$ subject to

$$0.5 \leq K_1 \leq 1.0$$

If average temperature >50°F (10°C) $K_2 = 1.0$

If average temperature <50°F (10°C) $K_2 = 0.6$

K_1 limits the increase in herbaceous fuel moisture due to precipitation. It is scaled to allow the X1000 value to respond the same as the 1000-h TL fuel moisture when the 1000-h TL fuel moisture is 25 percent or more.

K_2 reduces the response of the X1000 value to compensate for slower physiological processes in plants during cool weather. Figure 3 compares the 1000-h TL moistures with the X1000 value.

Prior to spring greenup, the herbaceous fuel is assumed to be completely cured, so the herbaceous fuel moisture (HFM) is equal to the 1-h TL fuel moisture.

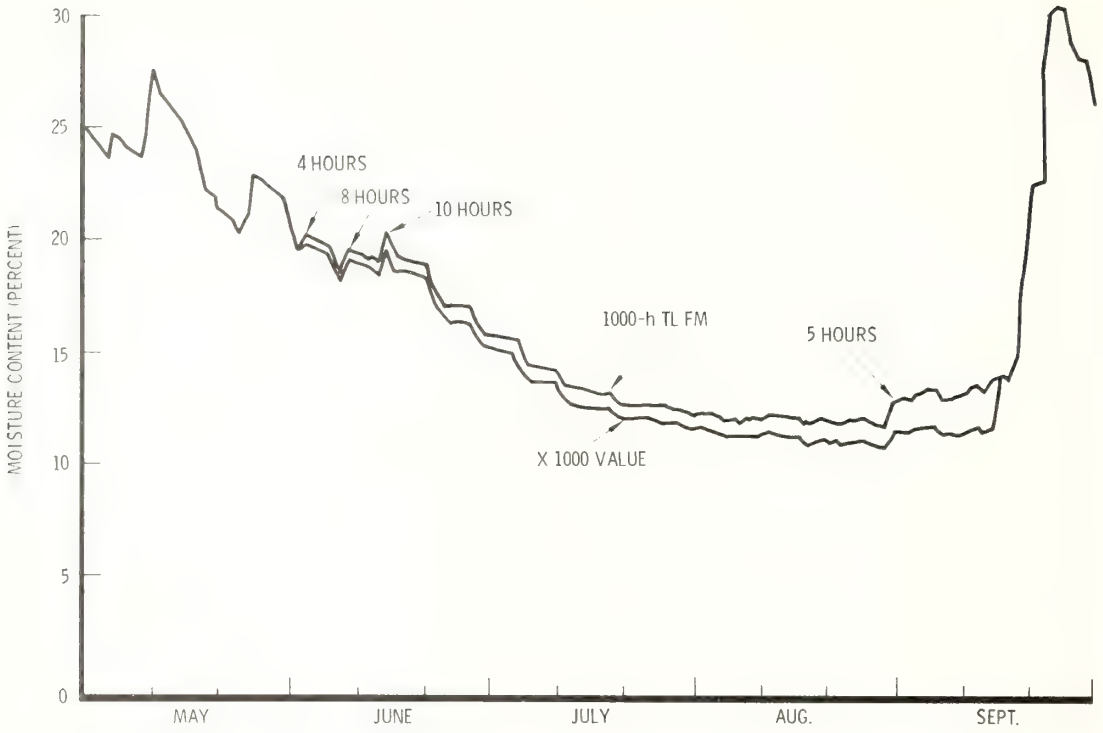


Figure 3.--Comparison of the X1000 value with the 1000-h TL fuel moisture computed from weather data recorded at Libby, Mont. 1973. Hours of precipitation for the four significant rainfall events are indicated.

During spring greenup, the live herbaceous fuel moisture increases gradually from the 1-h TL fuel moisture. A gradual greenup was built into the live fuel model at the request of users in the Eastern United States who feared that the "instantaneous" greenup originally proposed would not properly reflect the transition from high fire danger in early spring to low fire danger in summer. The length of the greenup period varies from 7 days for climate class 1, to 28 days for climate class 4. The length of the greenup was scaled to the climate class because plants growing in drier climates typically respond quicker to favorable growing conditions than do plants in wetter climates.

When a spring flush of growth becomes generally apparent, the user specifies the beginning of greenup. Then the herbaceous fuel moisture is calculated according to the equation:

$$HFM = FM1 + [(HERBGA + HERBGB * X1000) - FM1] * GREN$$

where:

HERBGA, HERBGB = climate dependent intercept and slope for annuals or perennials from table 3

X1000 = X1000 value

GREN = fraction of the greenup period that has elapsed.

FM1 = moisture content of the 1-h TL fuel.

If a second greenup occurs during a growing season, the X1000 value is again set equal to the 1000-h TL fuel moisture, and the same greenup procedure is followed, except the herbaceous moisture increases from its current value instead of the 1-h TL FM.

After the greenup period is complete, (GREN = 1.0) the herbaceous fuel moisture is calculated from:

$$HFM = HFPRGA + HFREGF \quad X1000$$

until the user specifies that the herbaceous vegetation has cured phenologically, or frozen.[5] Then the herbaceous fuel moisture is again equal to the 1-h TL fuel moisture.

Figure 4 illustrates the relationship between the X1000 value and the annual and perennial herbaceous moistures.

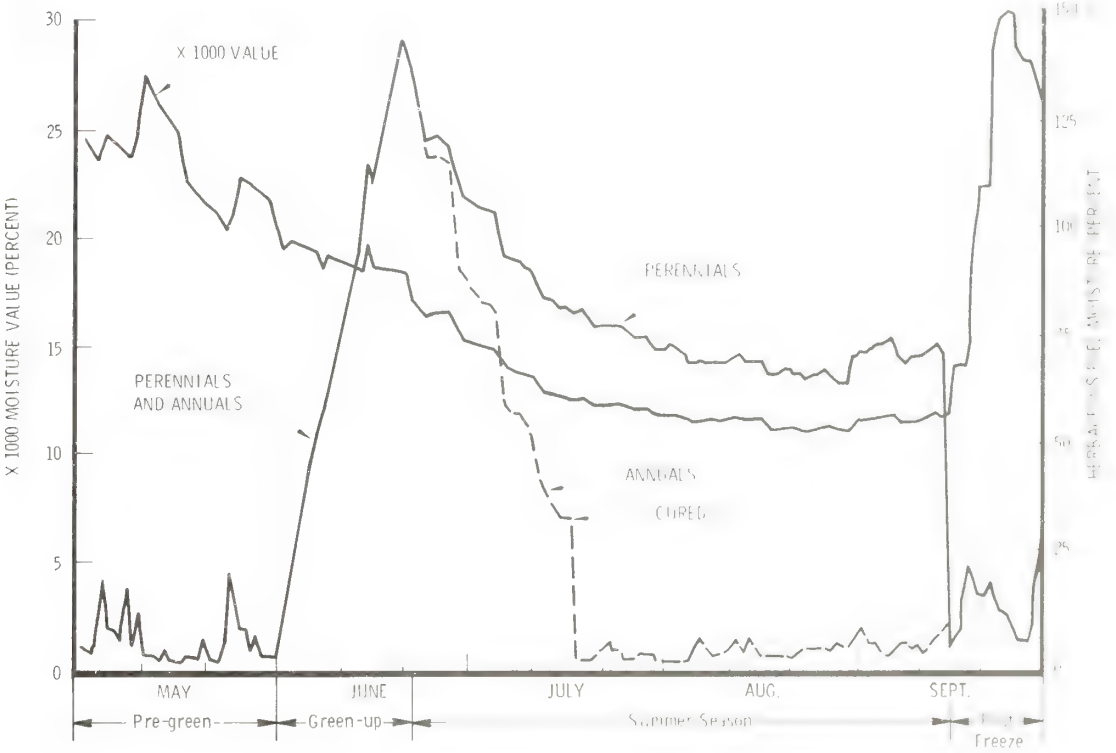


Figure 4.--An example of the relationship between X1000 value and moisture content of annual and perennial herbaceous plants. All herbaceous moisture follows the 1-h TL fuel moisture before green-up and after curing or freezing.

[5]"Green, cured" and "frozen" are always specified manually by AFFIRMS users. But in FIRDAT, which is used to process historical data, the user defines a date after which a freeze is possible. The specific date of the freeze is defined by one of two "freezing" criteria:

1. Five days (nonconsecutive) with a minimum temperature $\leq$ 32°F (0°C)
2. One minimum temperature $\leq$ 25°F (-4°C)

Transfer of Fuel Between Live and Dead Categories - All the herbaceous fuel load is included in the 1-h TL fuel load before greenup. During greenup, the live herbaceous fuel load is transferred from the 1-h TL to the live fuel category as the herbaceous moisture increases from 30 percent to 120 percent. The herbaceous fuel load is at its maximum and the 1-h TL fuel load at its minimum when the herbaceous moisture is greater than 120 percent.

As herbaceous plant moisture decreases later in the growing season, the load of *perennial* herbaceous fuels is shifted between the live and dead fuel categories as its moisture varies between 120 percent and 30 percent. This is the transition stage; 120 percent is an approximate value, serving as the upper limit for transition because it roughly defines the moisture content at which new growth is complete and the foliage is mature. Thirty percent was defined as the minimum moisture for transition because that is the approximate fiber saturation point, below which herbaceous plants are assumed to be dead.

For *annual* herbaceous plants, the process differs slightly. After greenup, the moisture content of annuals is *not* allowed to increase, so the fuel load for annuals then transfers from the live category to the dead category; never in the reverse direction as allowed with perennials. At 30 percent moisture content, all the herbaceous fuels have been added back into the 1-h TL class, i.e., after phenological curing or after a freeze in the fall.

The fuel load transfer equations are:

$$W1DP = W1D + WHERB * FCC$$

$$WHERBC = WHERB * (1.0 - FCC)$$

where: $FCC = -0.111 * HFM + 1.33$ and $0 \leq FCC \leq 1.0$

and W1DP = total load of 1-h TL fuel, including dead herbaceous fuel transferred to the 1-h TL category

W1D = load of the 1-h TL fuel before inclusion of any cured herbaceous material

WHERB = total load of herbaceous fuel

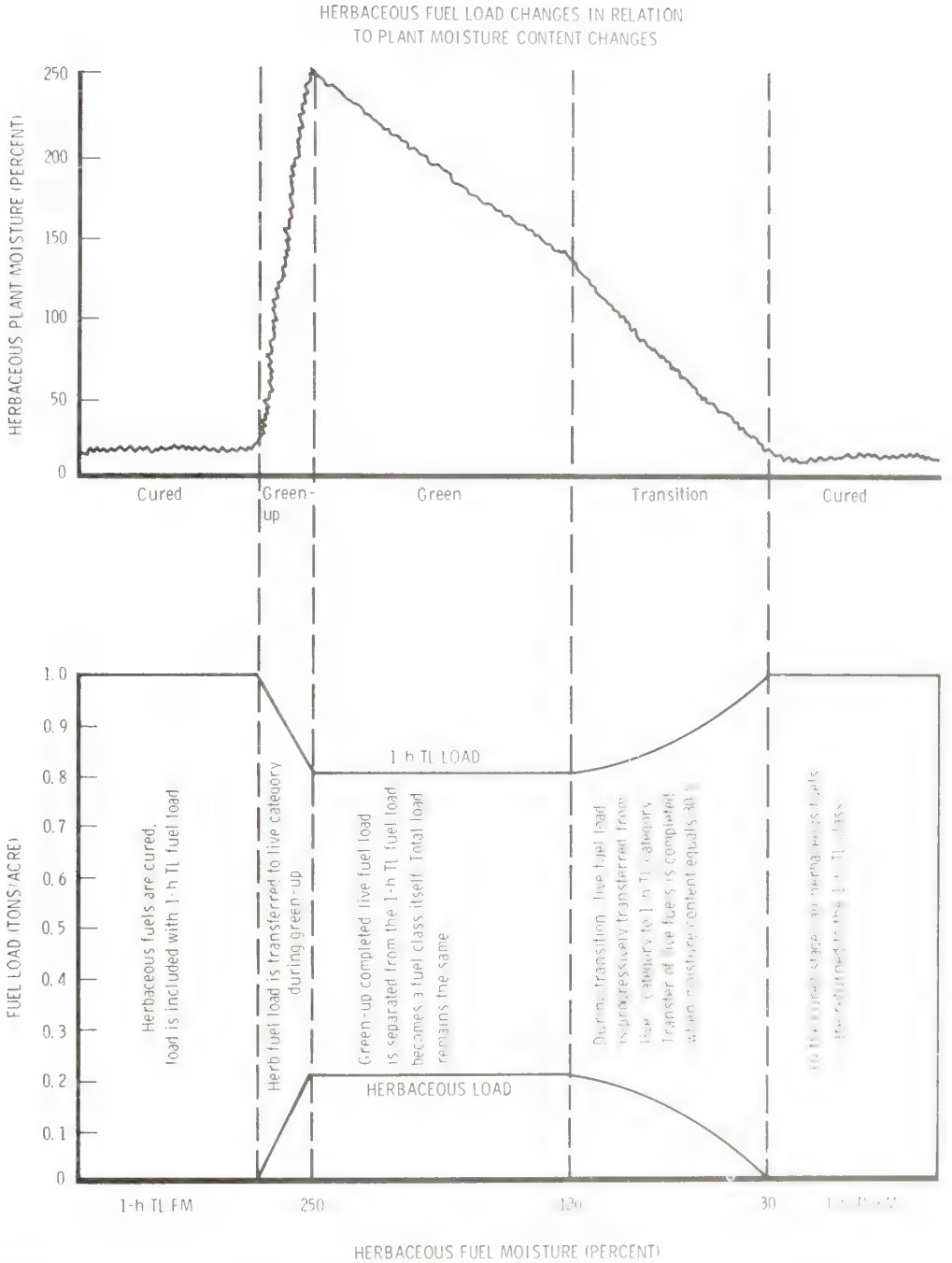
FCC = fraction of the herbaceous fuel that is to be transferred to the 1-h TL class

WHERBC = load of herbaceous fuel that is still green

HFM = herbaceous fuel moisture

Figure 5 shows herbaceous fuel load changes in relation to moisture content changes.

LIVE FUEL MODEL



Figures 6 and 7 illustrate examples of the transfer of fuel between the live and dead categories for perennial and annual grasses. Typically, herbaceous moisture will be somewhere near 250 percent at the completion of greenup. But these examples illustrate that given a dry spring or late greenup, the herbaceous moisture will peak at a lower value.

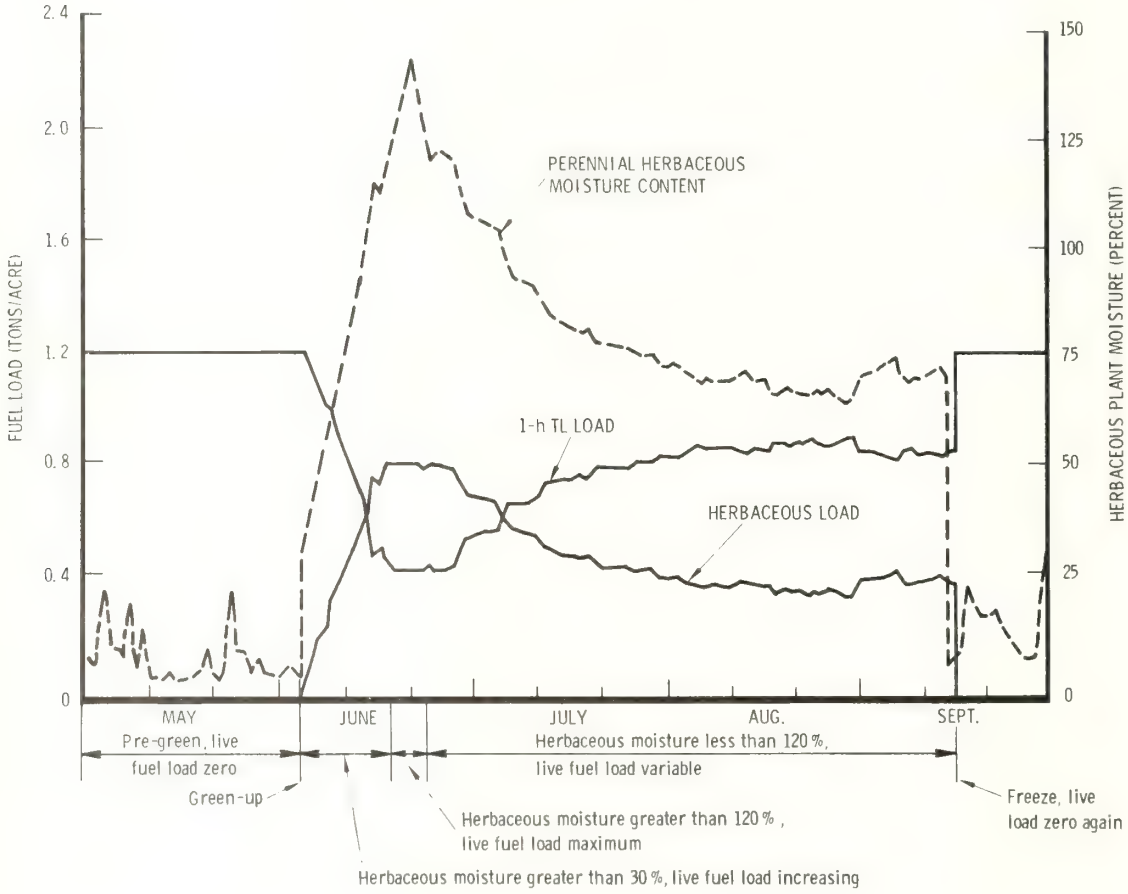


Figure 6.--The moisture content of live plants controls the transfer of fuel load between dead (1-h TL) and live herbaceous categories. The slope assigned to perennials prevents a complete transfer of fuel load from live to the 1-h TL category until a freeze occurs.

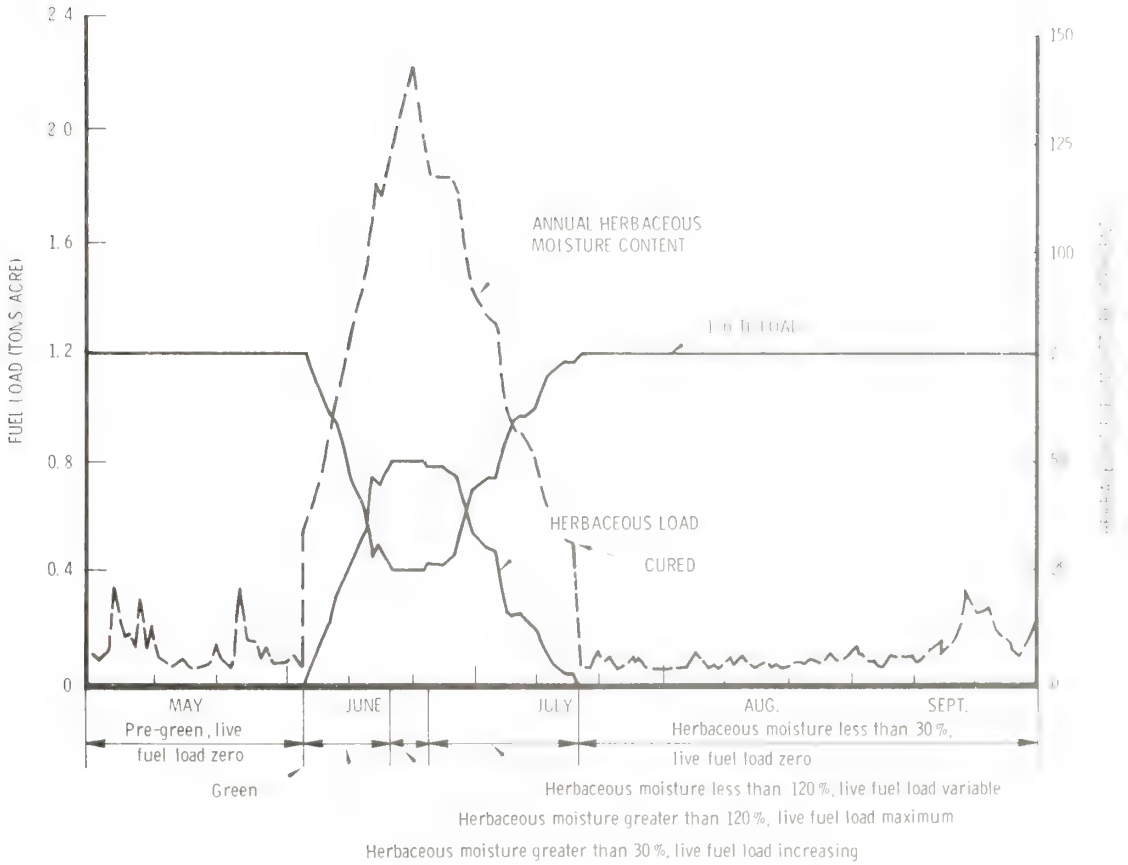


Figure 1.--After greenup, [illegible] in a rapid transfer of fuel load from the live herbaceous to the 1-h [illegible].

Woody Fuel Moisture Model

Prior to greenup in the spring, woody shrubs are assumed to be dormant, so the woody fuel moisture (WFM) is held constant. Measurements of chamise leaf moisture in southern California (Dell and Philpot 1965) indicate minimum values for woody plants in climate class 2 is about 60 percent. Likewise, measurements in the southeast (Blackmarr and Flanner 1968) suggest a minimum woody moisture of 70 percent for climate class 3. So depending on the climate class, pregreen WFM values are defined as 50, 60, 70, or 80 for climate classes 1, 2, 3, or 4 respectively. During spring greenup, woody moisture gradually increases from the pregreen minimum according to the equation:

$$WFM = PREGRN + [(WOODA + WOODB * MC1000) - PREGRN] * GREN$$

where: PREGRN = pregreen minimum moisture

WOODA, WOODB = climate dependent intercept and slope from table 3

MC1000 = 1000-h TL fuel moisture

GREN = fraction of the greening-up period that has elapsed

If a second green-up occurs during a growing season, the woody fuel moisture increases from its current value instead of from the pregreen value.

After greenup is complete, (GREN = 1.0) the woody fuel moisture is calculated from:

$$WFM = WOODA + WOODB * MC1000$$

until the shrubs become dormant. At that time the woody fuel moisture is set back to the minimum value specified by the climate class. Figure 8 illustrates a typical woody fuel moisture profile and its relation to the 1000-h TL fuel moisture.

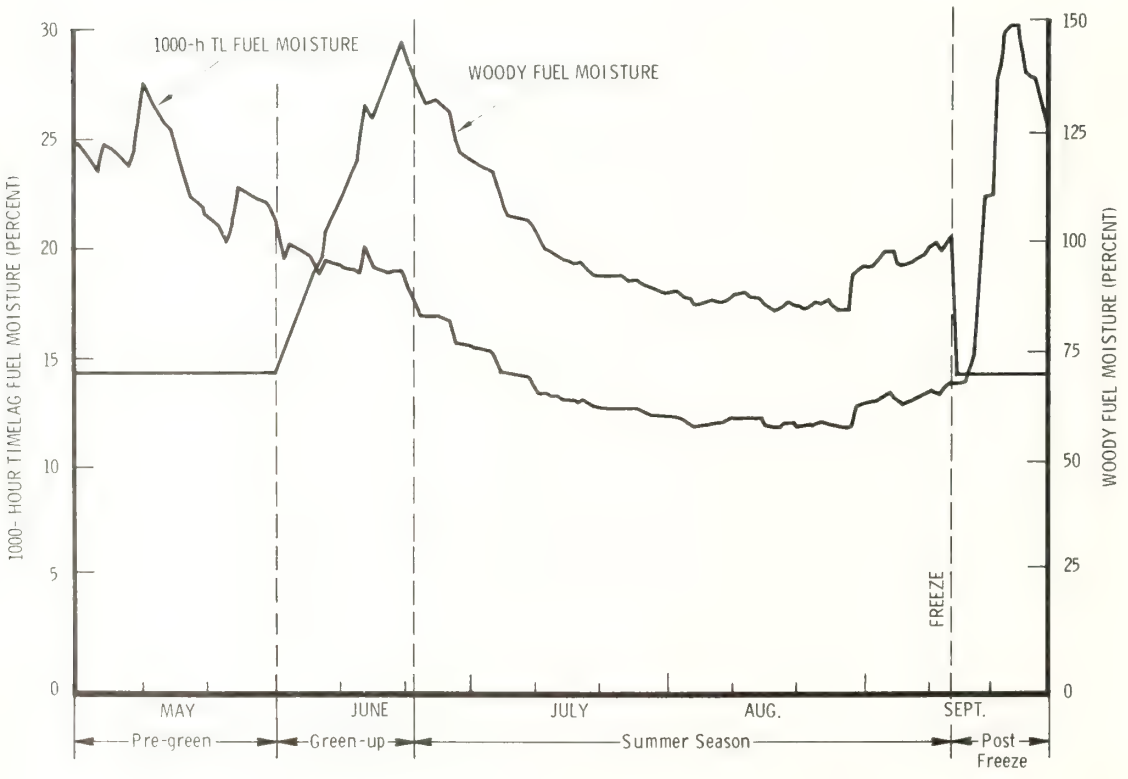


Figure 8.--Typical woody fuel moisture profile and its relation to the 1000-h TL fuel moisture.

APPLICATION OF THE LIVE FUEL MOISTURE MODEL

To apply the live fuel model, the following conditions must be met:

(1) Weather observations must be started at least 1 week prior to the date of greenup. This assures that the 1000-h TL fuel moisture has stabilized at a reasonable value for current weather conditions.

(2) Greenup must be defined at the proper time

(3) Herbaceous plants must be correctly designated as annuals or perennials.

(4) Climate class must be selected. The climate class should be selected for the location of the weather station. The choice of climate classes compensates for a lack of local live fuel moisture data.

The user has the capability to "tune" the live fuel model to produce live woody and herbaceous moisture profiles that are reasonable for his area. This can be done by designating herbaceous plants as annuals or perennials, and selecting the proper climate class.

Selection of Annual or Perennial Designation for Herbs and Forbs - Although the moisture content of annuals does not increase after greenup is complete, the live fuel model does assign the same *drying* rate to both annuals and perennials at moisture contents above 120 percent. During transition (HFM between 120 percent and 30 percent); however, annuals dry at a much faster rate than perennials. Thus, the live fuel model typically indicates a curing of annuals sometime during the summer season, but perennials do not cure until a freeze occurs. The annual designation should be used only if *more than half* of the herbaceous plants are annuals.

Selection of Climate Class - The user can affect live fuel moisture estimations through his selection of climate class. The effect of climate class selection on the moisture profile for perennial herbaceous grass is shown in figure 9. Climate class 3 is the proper selection for this data set. Normally, it is useful to test only one climate class above or below the one that is estimated to be appropriate for a particular fire weather station.

These controls provide the user with a great deal of flexibility to "tune" the live fuel model until it provides realistic moisture profiles for his area.

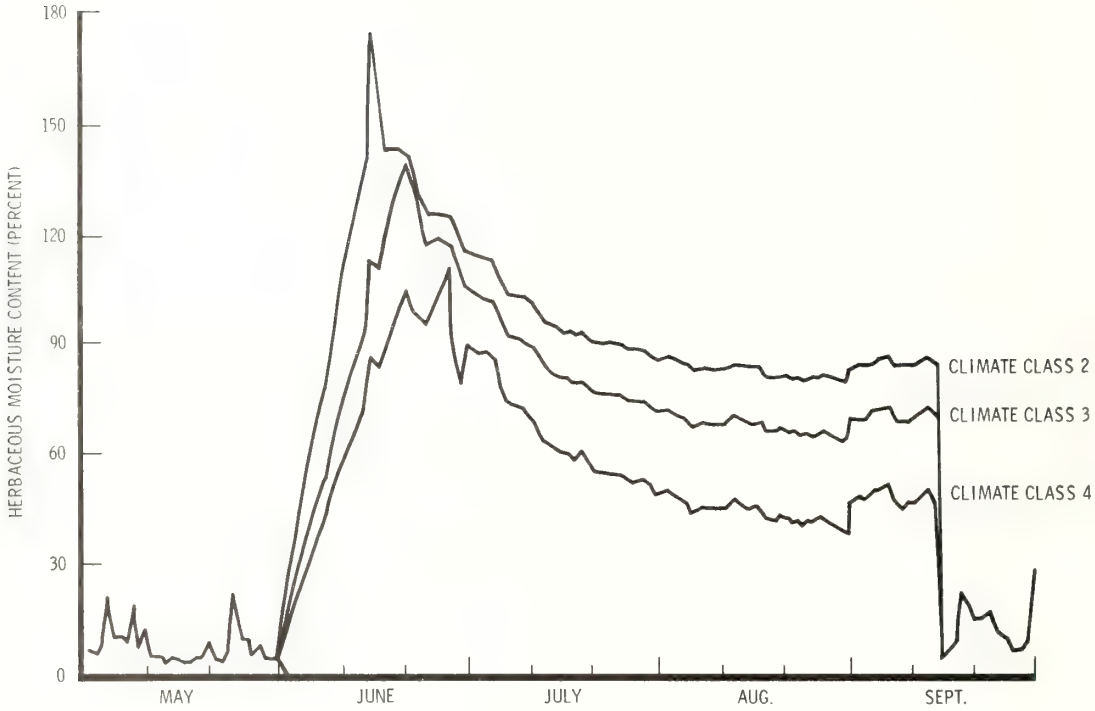


Figure 9.--Given the same weather, faster drying rates for higher numbered climate classes produce lower live fuel moistures for perennial herbaceous plants. Similar results would be obtained for annuals, with climate class 4 producing the earliest date of curing. Climate class 3 was the correct choice for this station.

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INYON GROWTH CHARACTERISTICS N THE SWEETWATER MOUNTAINS

. O. Meeuwig
. D. Budy

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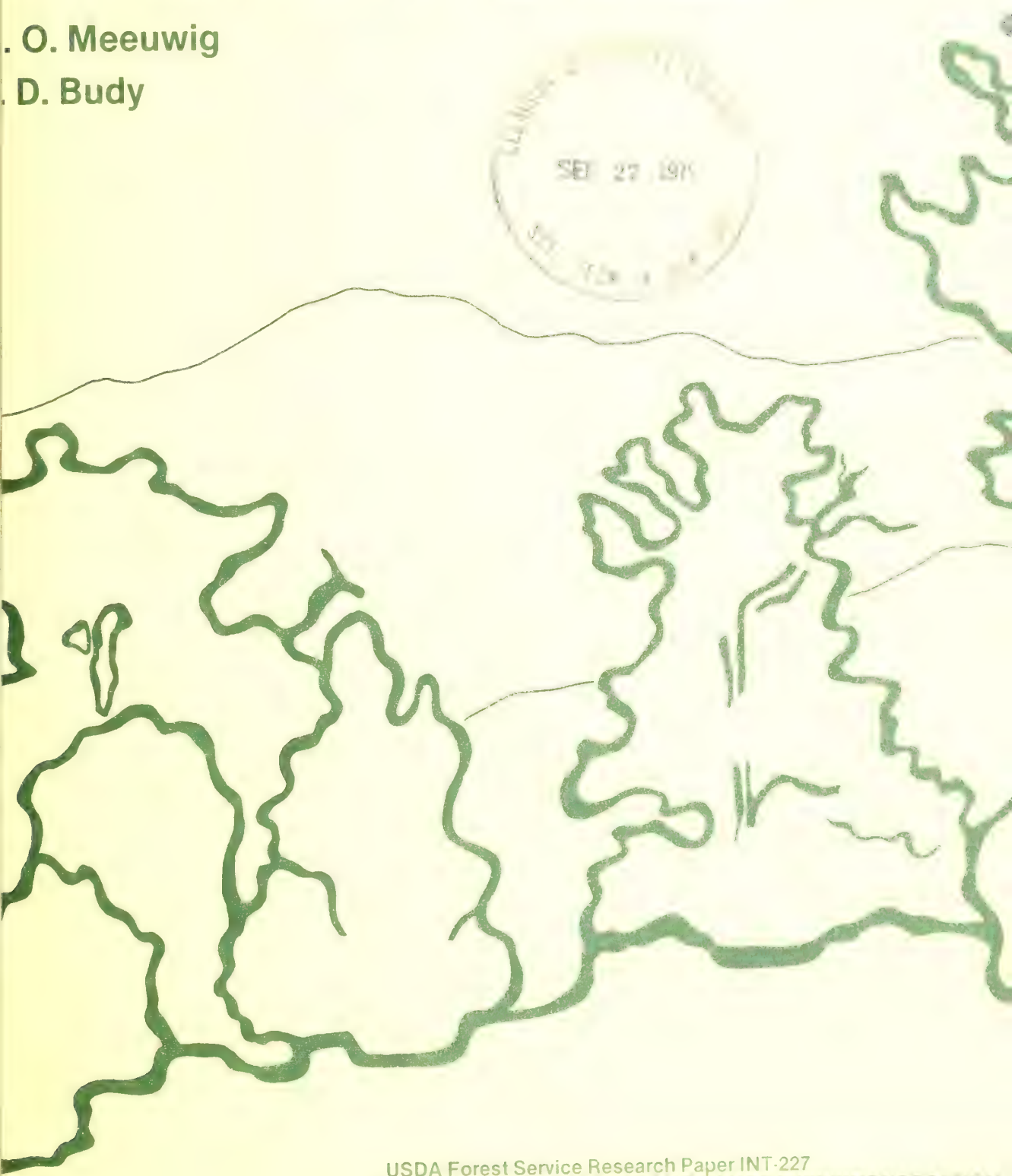

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE

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RESEARCH SUMMARY

Stem analyses of singleaf pinyon (*Pinus monophylla*) indicate that height growth rates of dominants and codominants are little affected by age or competition. Each tree grows in height at an essentially constant rate throughout most of its life, but height growth rates vary considerable among dominant trees on the same site. This variation is probably because of genetic differences. Diameter growth rate appears to be unaffected by age but is sensitive to competition. Stand basal area increases at an exponential rate until the understory shrubs are suppressed; then the rate of stand basal area increase becomes relatively constant. Stand biomass accumulation rates follow a similar pattern, tending to become constant after the understory shrubs have been suppressed.

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June 1979

PINYON GROWTH CHARACTERISTICS IN THE SWEETWATER MOUNTAINS

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and
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CONTENTS

	Page
INTRODUCTION	1
STUDY AREA AND PLOT DESCRIPTIONS	1
METHODS	3
RESULTS AND DISCUSSION	4
Height	8
Diameter	11
Stand Basal Area	14
Biomass	15
CONCLUSIONS	19
PUBLICATIONS CITED	20
APPENDIX I--Regression Equations for Present Biomass	21
APPENDIX II--Regression Equations for Past Biomass	22
APPENDIX III--Tree Data	23

INTRODUCTION

The singleleaf pinyon (*Pinus monophylla*) Utah juniper (*Juniperus osteosperma*) woodland of the Great Basin has had a long history of use; but because of the noncommercial status of the two species, there has been little research on their silvical characteristics. Reveal (1944) reported on the stand and tree characteristics of singleleaf pinyon and Utah juniper in the Pine Nut Range in western Nevada. Herman (1953, 1956) studied the phenology and growth characteristics of Utah juniper in central Arizona. Daniel and others (1966) made an extensive study of pinyon-juniper woodlands in Utah, Arizona, northwestern New Mexico, western Colorado, and eastern Nevada, but they dealt lightly with tree growth rates.

Other species of pinyon and juniper have received more attention than singleleaf pinyon and Utah juniper. Howell (1940) studied the growth and yield of Colorado pinyon (*Pinus edulis*), one-seed juniper (*Juniperus monosperma*), and Rocky Mountain juniper (*J. scopulorum*) in New Mexico and Arizona. The silvical characteristics of Colorado pinyon, Rocky Mountain juniper, and western juniper (*J. occidentalis*) were summarized in Agricultural Handbook No. 271 (Fowells 1965).

As the demand for firewood and other pinyon-juniper products continues to increase, the harvesting of these trees can be expected to increase dramatically, and more specific information will be needed for productive management of pinyon-juniper woodlands. In 1977, we began a study to obtain silvical information on singleleaf pinyon and Utah juniper. A secondary objective of the study has been to obtain data on intensively measured plots to provide standards for checking the accuracy of sampling methods that have been or will be developed for studying or inventorying pinyon-juniper stands.

This paper contains the results of the first year of study in a predominantly pinyon woodland in the Sweetwater Mountains along the California-Nevada border. Singleleaf pinyon growing in these mountains were studied to determine their rates of height and diameter growth in relation to tree age and competitive position, the basal area increment patterns of these pinyon stands, and the rates of wood, foliage, and aboveground biomass increments of both individual trees and stands. Similar data will be obtained on other pinyon-juniper woodlands in the Great Basin during the course of this project.

STUDY AREA AND PLOT DESCRIPTIONS

This study was made in a pinyon firewood sale area on the Bridgeport Ranger District, Toiyabe National Forest. The area is approximately 12 miles north of Bridgeport, California, between Green Creek and Frying Pan Creek on the east slope of the Sweetwater Mountains. Three plots--Green Creek, Cattle Trough, and Monte Cristo--were established in the study area; the aspect, slope, elevation, and percentage of overstory cover of each plot are presented in table 1. All three plots are on stony soils derived from rhyolitic colluvium. The stands at Green Creek were younger than those at Cattle Trough, but the oldest trees were found at Monte Cristo (table 2).

There has been a great deal of mining activity in the Sweetwater area and most of the stands are second-growth, dating from cuttings that furnished fuel and timber to the miners in the early 1860's (Wilson 1941). The absence of stumps in the area raises some question as to the past cutting, but Lord (1883) reported that Chinese laborers followed the woodcutters, pulling up the stumps, roots, and shrubs from the cutover hills.

Table 1.--*Aspect, slope, elevation, and overstory cover of the Sweetwater plots*

Plot name	Aspect	Slope	Elevation	Overstory cover
		Percent	*Meters*	*Percent*
Green Creek	N80°E	5	2200	49
Cattle Trough	N40°E	20	2100	64
Monte Cristo	S60°E	15	2300	60

Table 2.--*Age distribution of trees more than 1 m tall on the Sweetwater plots*

Age class (Years)	Green Creek	Cattle Trough	Monte Cristo
41- 50	2		
51- 60		3	1
61- 70	10	1	1
71- 80	7	8	8
81- 90	9	6	8
91-100	2	3	1
101-110		4	2
111-120		5	3
121-130	1	1	1
131-140		5	1
141-150	1	6	1
151-160	2	9	
161-170		6	3
171-180		6	
181-190			
191-200	1	1	
241-250			1
251-260			1
261-270			1
431-440			1
All trees	35	64	34

Each plot is 30 m square with an area of 900 [illegible]. Almost [illegible] singleleaf pinyon; a few juniper [illegible] are on or near the plots. Several Jeffrey pine (*Pinus jeffreyi*) are in the vicinity of the highest plot (Monte Cristo), but none are on or immediately adjacent to the plot.

Closed stands were deliberately chosen so that the influence of understory vegetation on tree growth would be negligible. The understory was sparse and of low vigor, especially on the lower two plots. Ephedra (*Ephedra viridis*), bitterbrush (*Purshia tridentata*), and mountain mahogany (*Cercocarpus ledifolius*) were the principal understory species on the Monte Cristo plot. Sagebrush (*Artemisia tridentata*) and gooseberry (*Ribes velutinum*) were the principal understory species on the other two plots.

METHODS

The boundaries of the 30 m by 30 m plots were laid out with staff compass and tape. Control lines at 5 m intervals parallel to the lower boundary were used in the mapping of tree stem locations and crown outlines. The foliage class of all trees taller than 1 m was estimated on a scale of 1 to 9. A vigorous tree with dense foliage on all sides was rated 9, and a tree with very sparse foliage was rated 1.

All trees taller than 1 m were felled and their total height (including stump) was measured with a tape. Stump height was about 15 cm for all but a few trees that could not be cut at that height because of large limbs or other irregularities.

From 6 to 9 trees on each plot, representative of the range in stump diameters, were selected for weighing. Each of these trees was separated into four components that were weighed with a load cell on a boom mounted on a pickup truck. The four components were:

1) live material larger that 76 mm diameter outside bark (d.o.b.),

2) live material 25 to 76 mm d.o.b.,

3) foliage and other live material smaller that 25 mm d.o.b.,

4) deadwood.

The relative proportions of foliage, twigs less than 6.4 mm d.o.b., and branches 6.4 to 25 mm were determined by subsampling about 10 percent of the <25 mm component. Cross-sectional disks were taken of each of the components and, along with samples of foliage and twigs, were analyzed in the laboratory for moisture content and bark percentage. These data were used to calculate ovendry mass of foliage, ovendry mass of wood larger than 76 mm, and total aboveground ovendry biomass in each tree.

On the weighed trees, stem sections were taken at stump height and at approximately 1-m intervals on the dominant stem up to a 3-cm diameter on the dominant leader. On the unweighed trees, stem sections were taken at the stump, at 3 cm on the dominant leader, and at one or two intermediate points on the dominant stem. The annual rings on all of these sections were counted and height-age curves were plotted for each tree. These curves were extrapolated to ground level to estimate tree age, and interpolated to determine past height at any particular time. False rings and missing rings are known to occur in pinyon and can make age determinations difficult, but comparisons of ring width patterns among trees and with Bridgeport precipitation data failed to indicate either false or missing rings in the trees on the Sweetwater plots.

Stump diameters, both inside- and outside-bark, were measured with a diameter tape. If there was more than one stem at stump height, the diameter of each stem was measured and the equivalent stump diameter was calculated by:

$$D = \sqrt{D_1^2 + D_2^2 + \ldots D_n^2},$$

(eq. 1)

in which D is the equivalent diameter and the subscripted D's are individual stem diameters.

Since pinyon butt cross-sections are usually out of round and the width of each annual ring is rarely uniform, it was necessary to develop special procedures to determine past diameters. Each stump cross-sectional disk was inspected and a line was drawn on the radial that appeared to best represent the growth pattern. Ring widths were measured to the nearest 0.1 mm along this line. The stump diameter (outside bark) at any particular time in the past was calculated by:

$$D_t = \frac{D_p \sum_t r_i}{\sum_p r_i}$$

(eq. 2)

in which D_t is past diameter (outside bark) at any time t, D_p is present diameter (outside bark), $\sum_t r_i$ is the sum of the ring widths from the pith to time t, and $\sum_p r_i$ is the sum of all ring widths along the radial line on the section. This equation corrects for changing bark thickness and for systematic errors in the measurement procedure.

Foliage, wood larger than 76 mm diameter, and total aboveground biomass of all unweighed trees were calculated using regression equations developed from data obtained in a companion study[1]. These equations are based on 68 pinyon trees, 18 of which are weighed trees from the Sweetwater plots. The remaining 50 are from 13 study sites throughout Nevada. Input variables include stump diameter, crown diameter, height, and foliage class. These equations are presented in appendix I.

Past biomasses (foliage, wood, and total) of each tree were estimated for each decade from 1860 to 1970, and for 1965 and 1975. These biomasses were calculated using regression equations that expressed past biomass as a function of present biomass and past height, diameter, and age. These equations, which were also derived from data obtained in the companion study, are presented in appendix II.

Basal area per hectare and biomass per hectare for each plot through time were calculated by adding the values for the individual trees and dividing the sum by the plot area (0.09 ha).

RESULTS AND DISCUSSION

Comparisons of tree sizes, ages, and diameter growth rates (appendix III) with their relative locations (figs. 1, 2, and 3) indicate varying degrees of competition among trees and suppression of the smaller trees. This paper will deal primarily with the growth of dominant and codominant trees and with the growth of stands, postponing a more detailed discussion of competition to another paper after more data have been acquired.

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[1]Miller, E. L., J. D. Budy, and R. O. Meeuwig. Biomass of singleleaf pinyon and Utah juniper (manuscript in preparation).

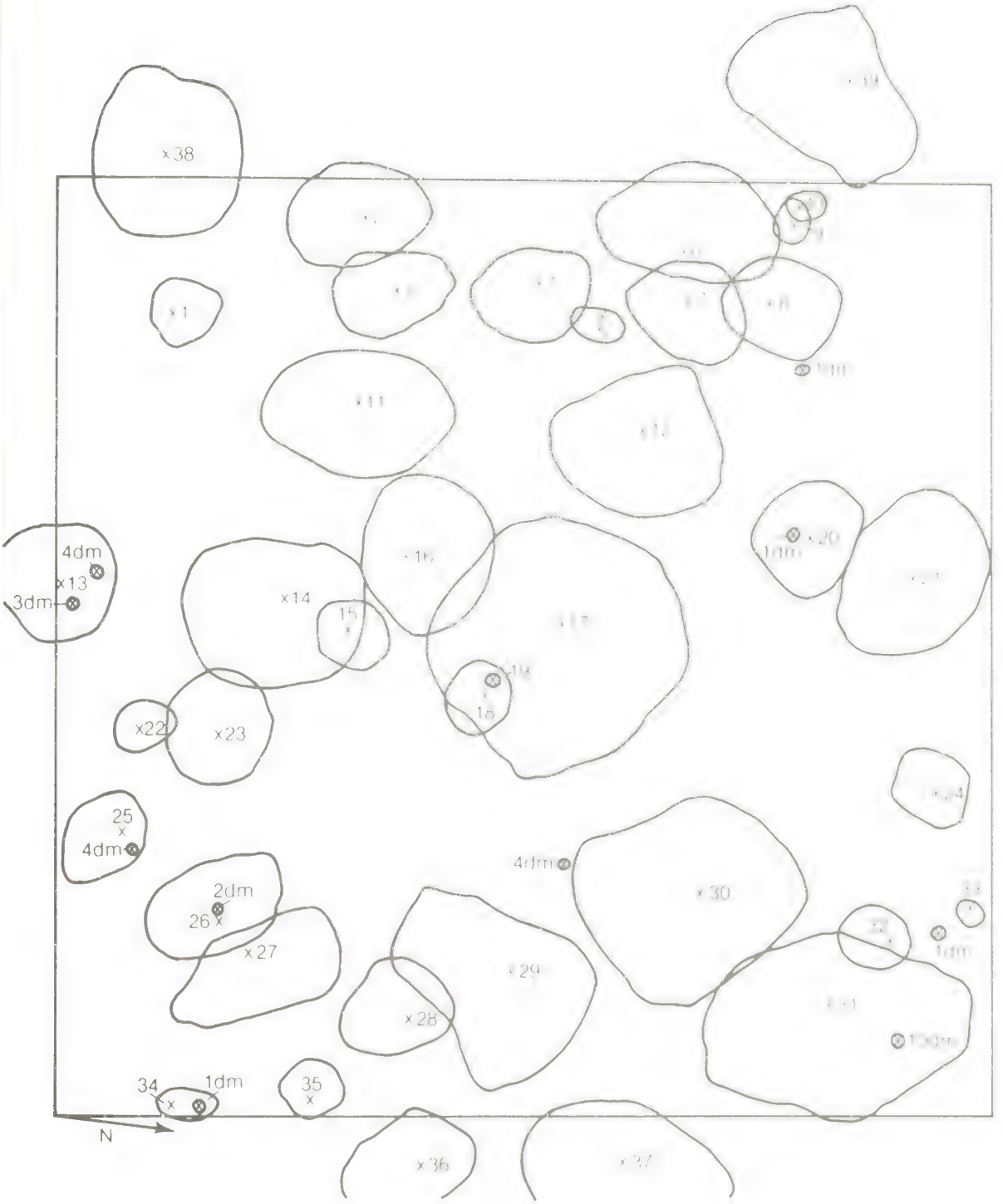


Figure 1.--Map of crown outlines and stump centers on the [illegible] taller than 1 m are numbered. The heights of the unnumbered [illegible] map in decimeters (dm).

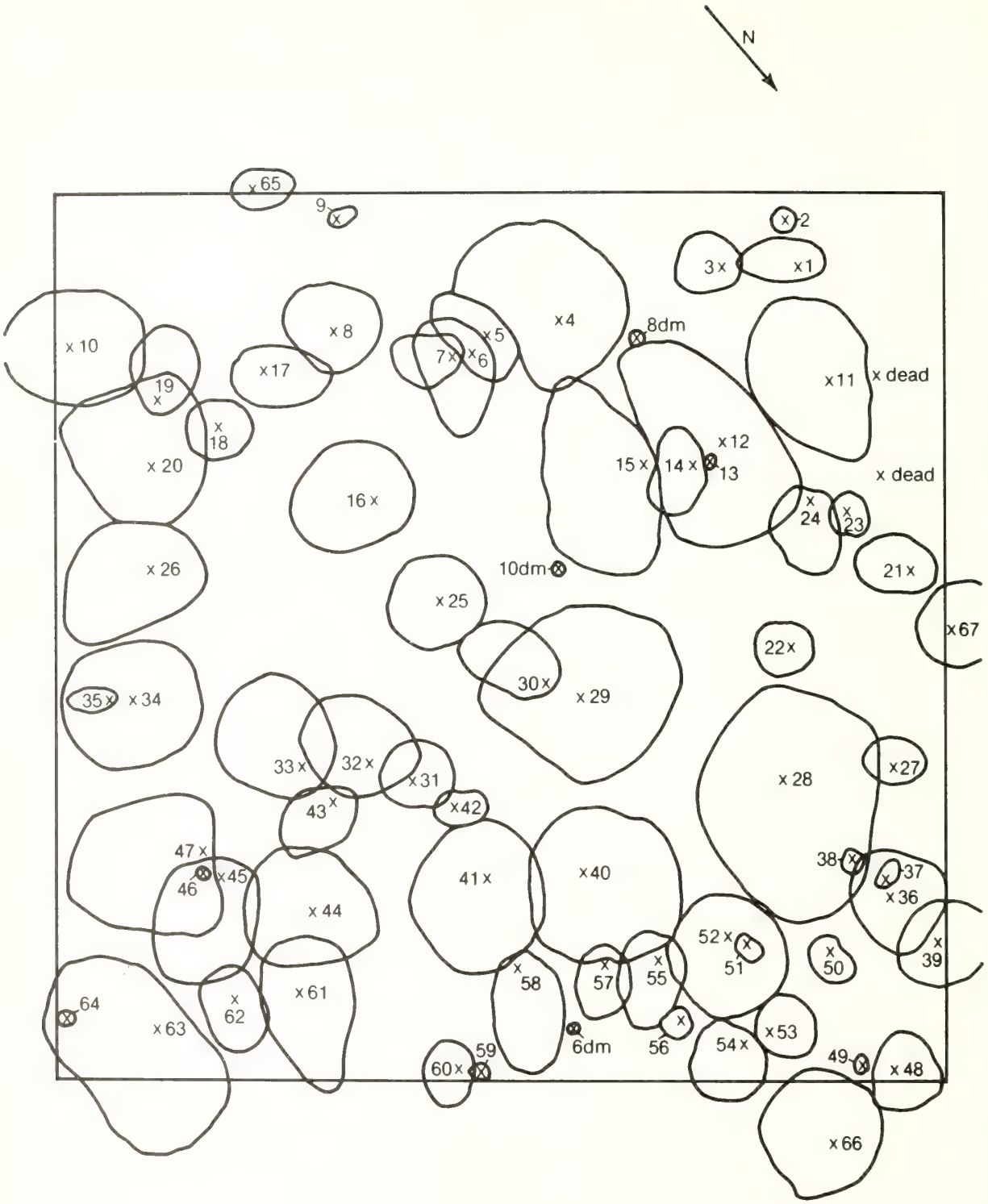


Figure 2.--Map of crown outlines and stump centers on the Cattle Trough plot. All trees taller than 1 m are numbered. The heights of the unnumbered trees are noted on the map in decimeters (dm).

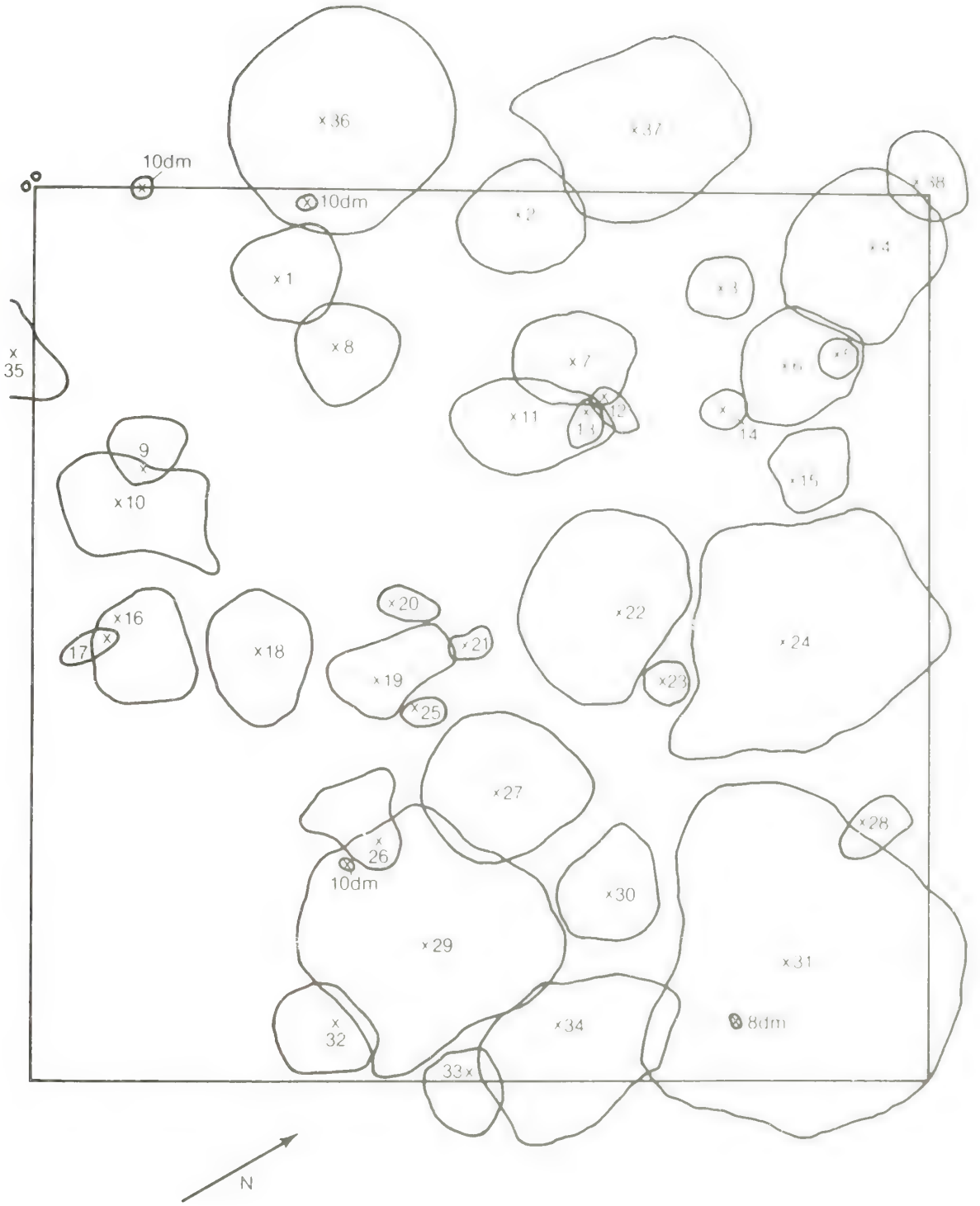


Figure 5.--Map of stream cattails. Clumps of stems taller than 1 m are numbered. The heights of the unnumbered clumps are given on the map in decimeters (dm).

Height

Tree heights of several dominants and codominants on each plot are shown through time in figures 4, 5, and 6. Each dot represents a measurement of a cross-sectional disk. The dots are connected by straight lines for simplicity. Few of these curves approximate the conventional S-curve, in which height growth increases initially and then tends to decrease as the tree matures. Most of the trees have had fairly constant height growth rates throughout their lives with a tendency for slightly lower initial growth rate. None appear to be approaching culmination of height growth. Tree #27 at Green Creek (fig. 4) and tree #32 on the Cattle Trough plot (fig. 5) come the closest to the conventional S-curve but #27 is still a young tree and the height growth rate of #32 does not appear to have decreased in the past 70 years.

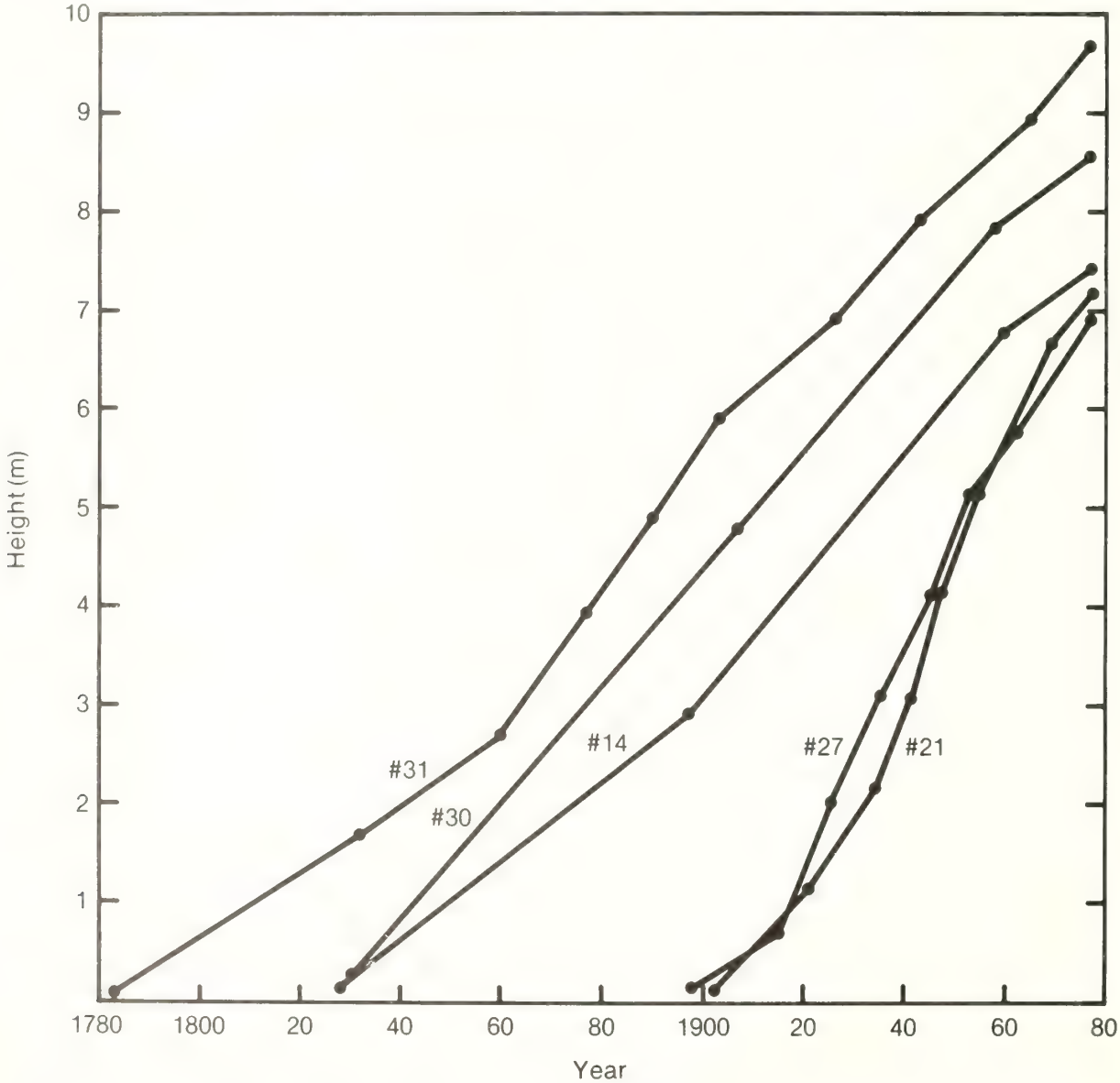


Figure 4.--Heights of five dominant and codominant pinyons on the Green Creek plot from 1780 to 1977. Tree #6 is not shown because its curve coincides with those of trees #21 and #27.

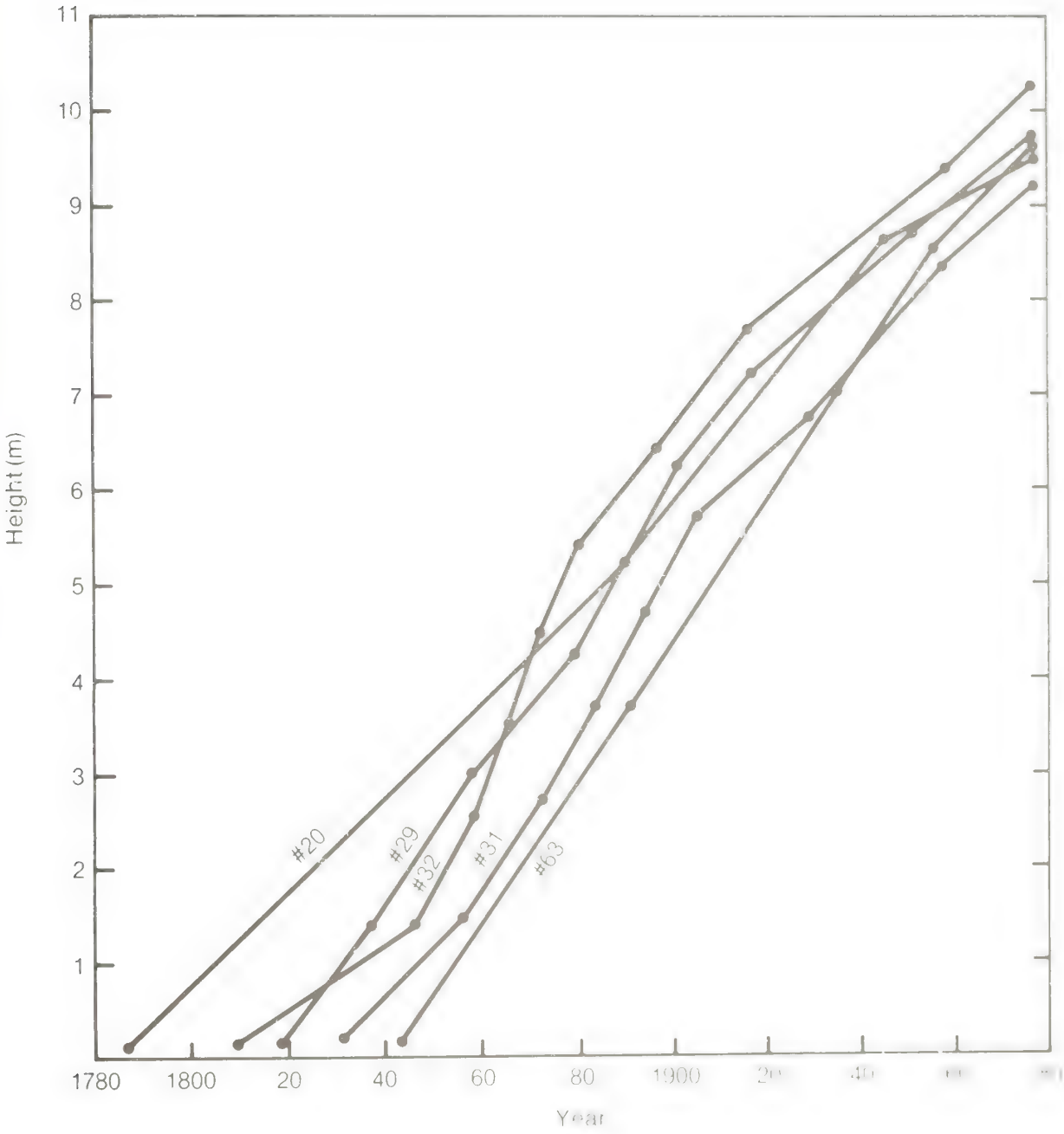


Figure 5.--Heights of five dominant and codominan
from 1780 to 1977.

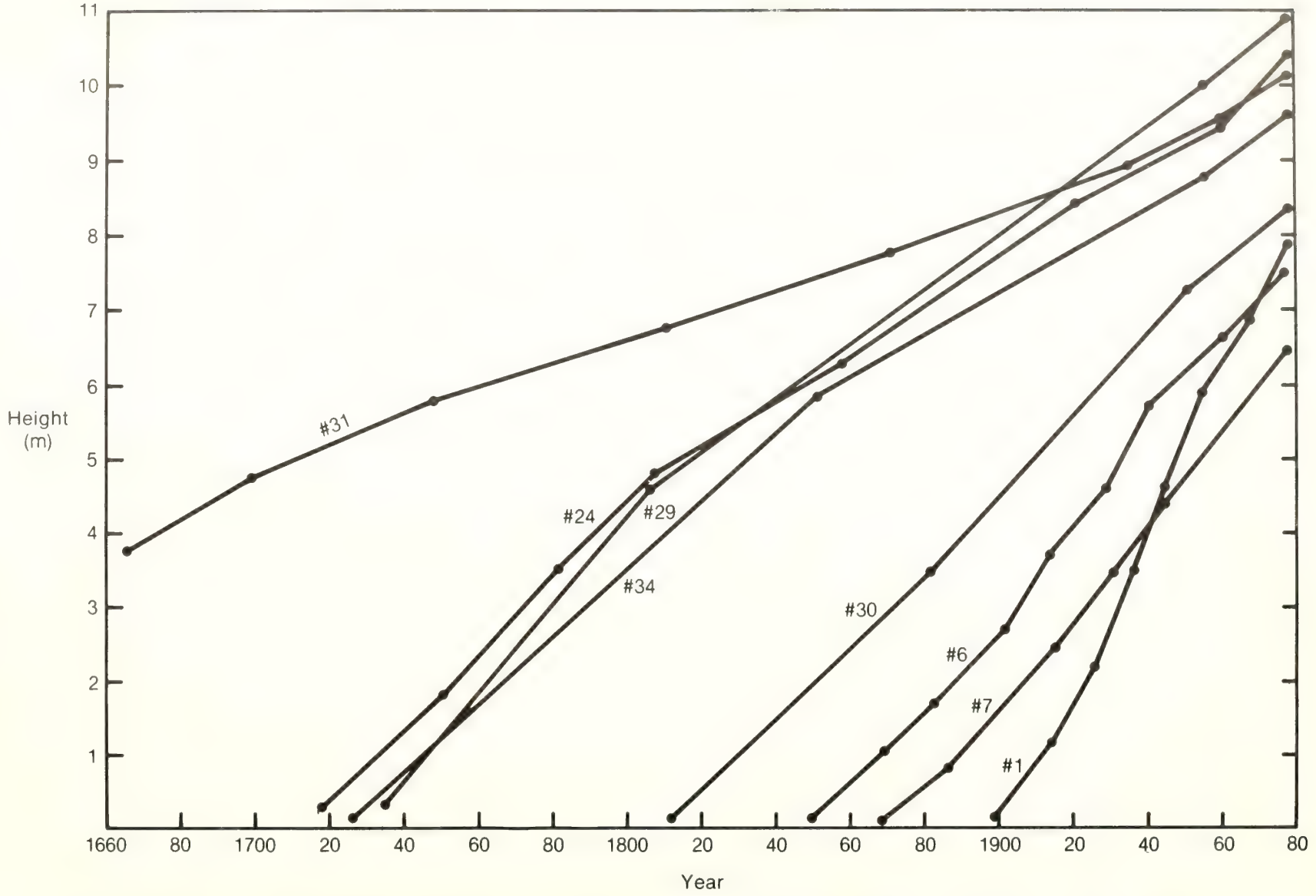


Figure 6.--Heights of eight dominant and codominant pinyons on the Monte Cristo plot from 1660 to 1977.

Height growth rates vary considerably among dominants on the same plot, as on the Monte Cristo plot. The younger dominants are growing faster than the older trees are growing now or grew at the same age. It is probable that these faster-growing trees are genetically superior, but where are their parents? Pinyons taller than 12 m are rare in the study area and in most other pinyon-juniper stands in the Great Basin. A plausible explanation of this anomaly is that faster-growing trees were present in the stands but were logged off in the 19th century, leaving the shorter (slower-growing) trees that are now the oldest trees in the stand.

Diameter

Stump diameters of several dominants and codominants on each of the three plots are plotted through time in figures 7, 8, and 9. The diameters were calculated at 10-year intervals through 1960 and then at 5-year intervals until 1975. The Cattle Trough plot (fig. 8) has the expected S-curves: diameter growth increased initially and then decreased as competition among trees increased. Trees #31 and #32 on this plot provide a good example of the effects of competition. These trees are close together (fig. 2) and obviously in competition. As these trees developed and competition between them increased, diameter growth of both decreased but the reduction was greater in the younger, smaller tree (#31). The competition had no apparent effect on height growth rates of either tree (fig. 5).

In contrast to the Cattle Trough plot, none of the dominants and few of the codominants on the other two plots have S-shaped curves (figs. 7 and 9). The diameter growth rates of most of these trees have remained essentially constant from the time they attained a diameter of about 10 cm up to the time they were felled and measured. In general, the larger trees on these two plots are not competing with each other but with smaller trees. In the absence of appreciable competition, there appears to be no diminution of diameter growth regardless of tree size or age. The older trees on the Monte Cristo plot demonstrate this point. Tree #34 is suffering from competition with trees #29 and #31, but trees #24, #29 and #31 have essentially straight-line diameter growth (fig. 9).

Tree #31 on the Monte Cristo plot is a special case that requires further explanation. Unfortunately, the butt of this old tree was badly rotted and it was necessary to extrapolate the radial growth pattern of a section 2 m high on the dominant stem to calculate past diameters at stump height. Thus, the past diameters plotted for this tree are based on the assumption that the ratio of radial growth at 15 cm to radial growth at 2 m is constant. In any case, diameter growth of this tree has been essentially constant for more than three centuries.

Reveal (1944), reporting on a study in the nearby Pine Nut Range, stated: "Diameter growth (of pinyon) is maintained at approximately one inch per decade for the first 100 years. As maturity advances, the diameter growth decreases to 0.25 inch at the end of the second century. The life span is seldom over 250 years."

The results from the Sweetwater Mountains indicate that average diameter growth of pinyons is roughly 1 in (25 mm) per decade but that competition, not age, is the primary cause of reduction in diameter growth. These results also suggest that the natural life span of singleleaf pinyon can be well over 250 years.

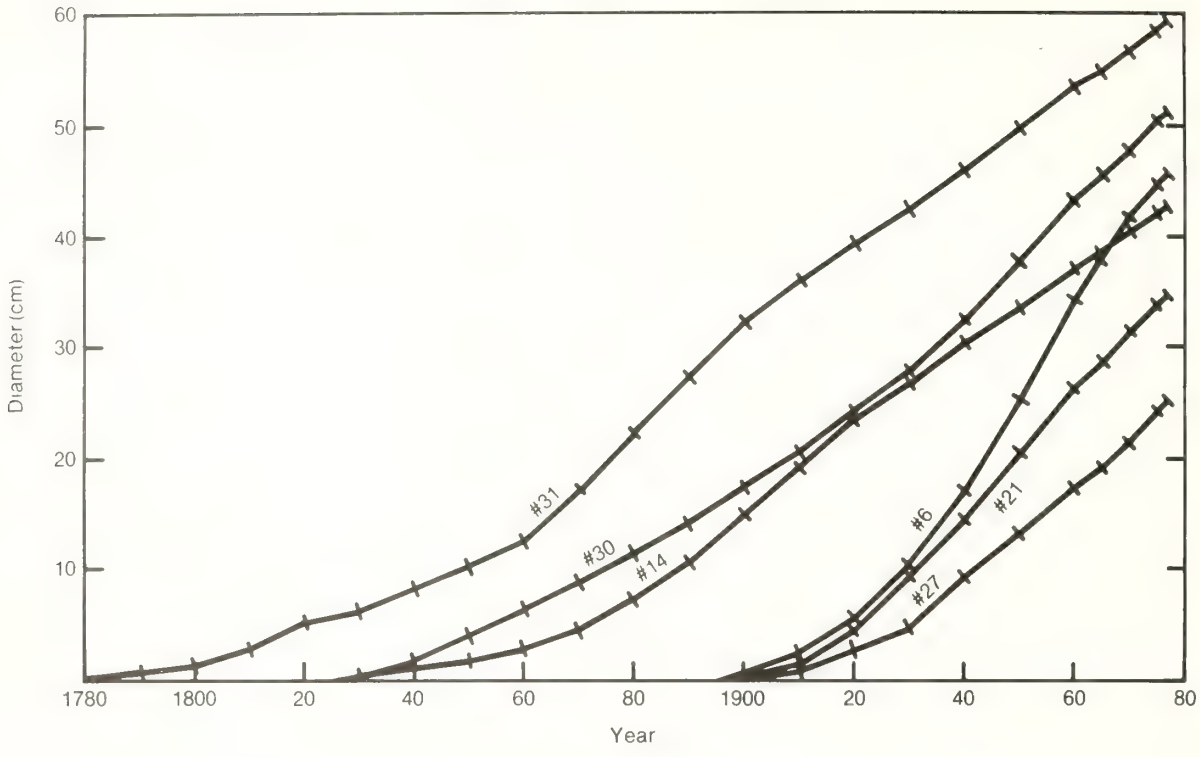


Figure 7.--Stump diameters (outside bark) of six dominant and codominant pinyons on the Green Creek plot from 1780 to 1977.

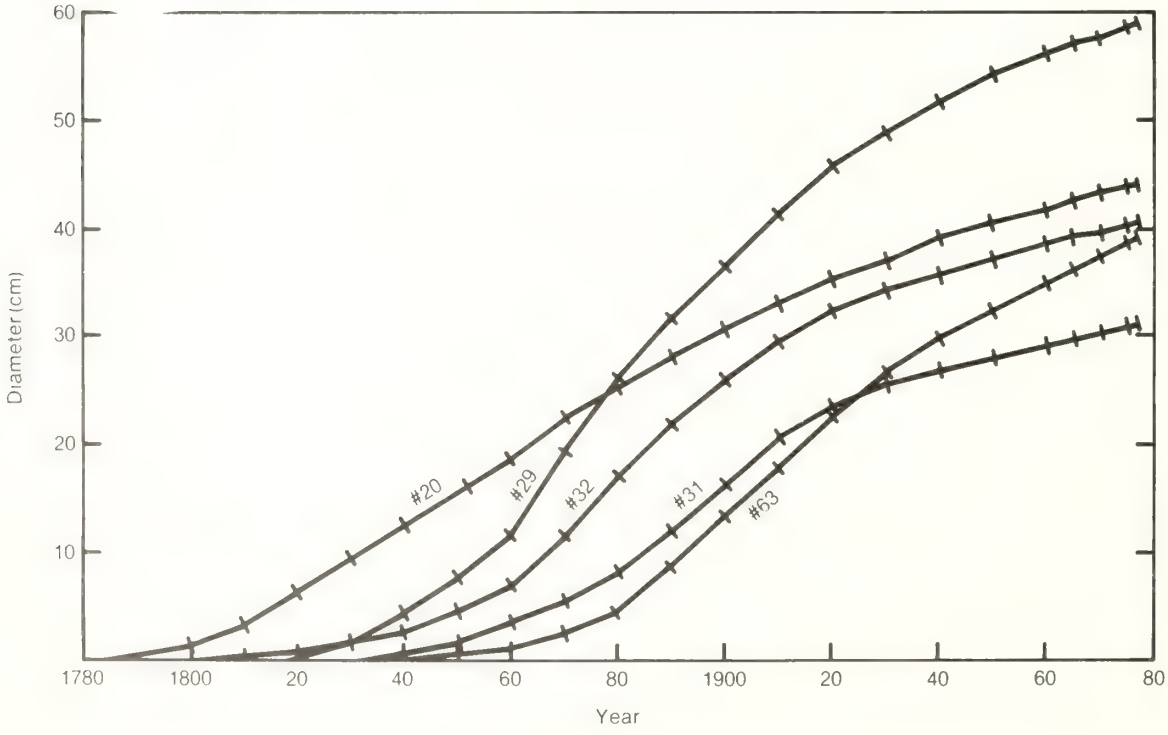
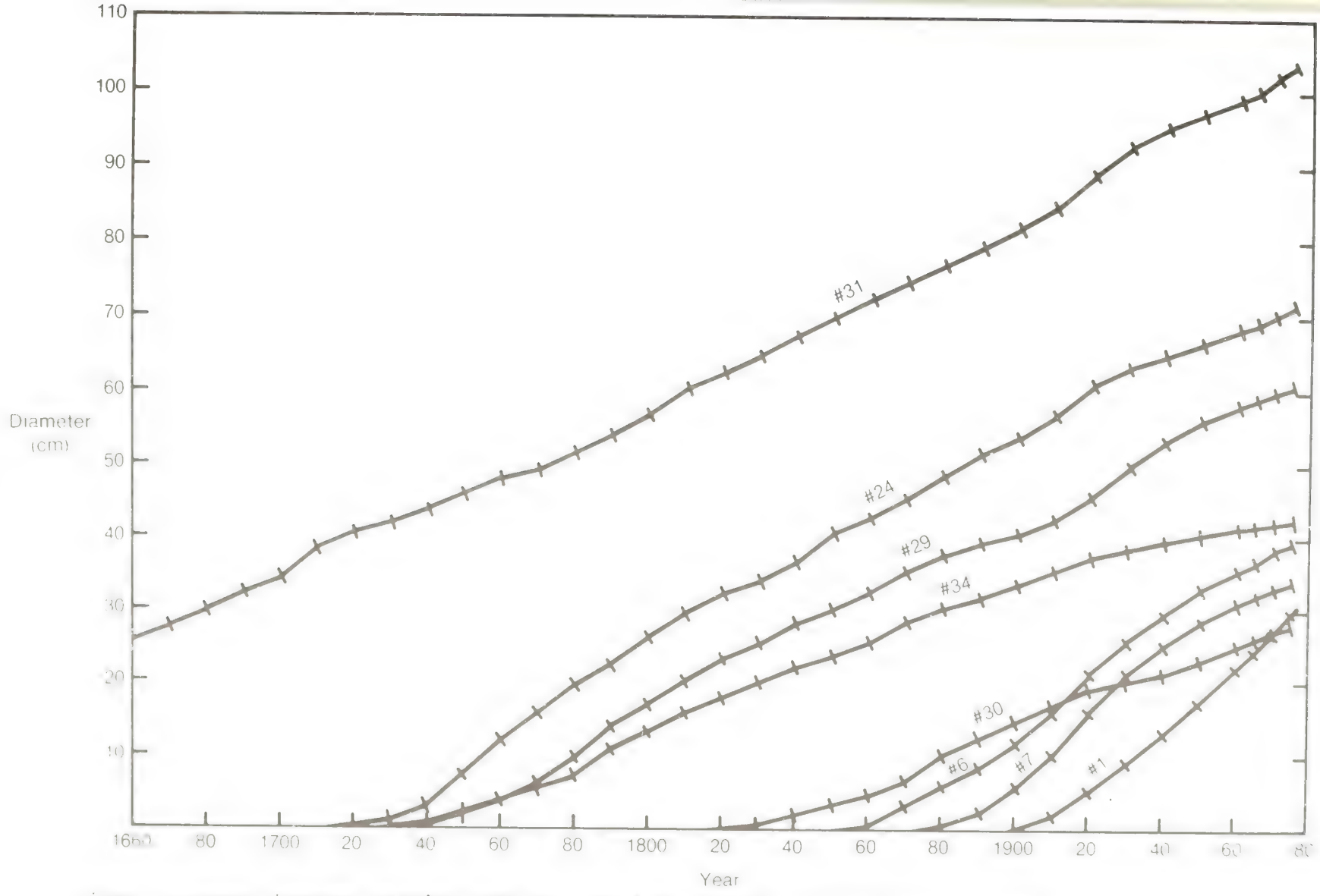


Figure 8.--Stump diameters (outside bark) of five dominant and codominant pinyons on the Cattle Trough plot from 1780 to 1977.


110
100
90
80
70
60
50
40
30
20
10
Diameter (cm)
#31
#24
#29
#34
#30
#6
#7
#1
1660
80
1700
20
40
60
80
1800
20
40
60
80
1900
20
40
60
80
Year

Stand Basal Area

Patterns of stand basal area increase are similar on all three plots (fig. 10). Stand basal area growth rate gradually increases until the trees achieve virtually complete dominance and then the rate of increase becomes constant. When the rate becomes constant, the understory is reduced to a few plants that have negligible competitive effects on the trees, and the stand can be considered closed. The constant rate of basal area growth of closed stands is probably closely linked with site potential. The growth rates prior to stand closure depend on density of trees and size distribution as well as site potential.

Obviously, there must be an upper limit on stand basal area and the rate of stand basal area growth must decrease as this limit is approached. However, there is no indication of such a decrease on these three plots. A slight decline in growth rate from 1975 to 1977 can be discerned in figure 10 and in some other figures, but this apparent decline is attributed to unusually dry conditions during this period and to the fact that the trees were cut and measured before they had completed their 1977 growth.

Pinyon trees grow so slowly that several centuries may be required to reach the upper limit on stand basal area. Few pinyon-juniper stands in the Great Basin are old enough to be approaching this limit.

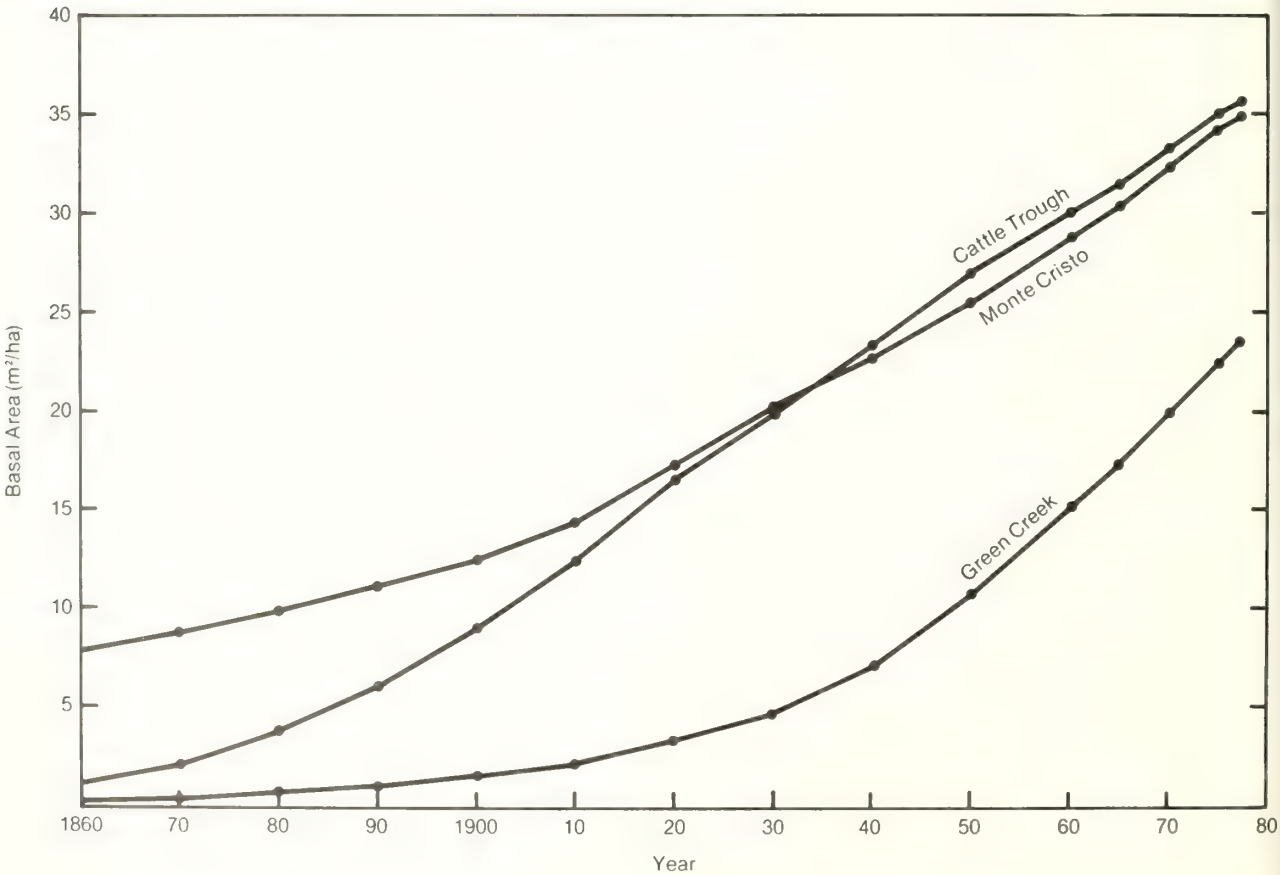


Figure 10.--Stand basal area on each of the plots from 1860 to 1977.

Biomass

Biomass components (foliage, wood larger than 76 mm diameter, and total above-ground biomass) of all trees taller than 1 m are tabulated in appendix III. Past values of these biomass components were calculated for all trees, using the regression equations in appendix II. The results of these calculations for the largest tree on each of the three plots are portrayed in figures 11, 12, and 13.

Tree #31 on the Green Creek plot (fig. 11), despite its small size in 1860, was about 78 years old at the time. Apparently, it had been suppressed, perhaps by a stand of trees that were removed about that time. If so, it responded favorably to release.

Tree #29 on the Cattle Trough plot (fig. 12) was about 40 years old in 1860 and showed no evidence of overstory suppression or competition until about 1920 when its growth rate began to decline. Unlike tree #31 at Green Creek, tree #29's foliage biomass has remained nearly constant during the past 40 years.

One of the interesting things about tree #31 on the Monte Cristo plot (fig. 13) is its lack of senescence. Its rates of diameter and height growth have not changed appreciably over the past 300 years. Up until the time the tree was measured, its rate of biomass accumulation still tended to increase somewhat, even though it was more than 400 years old.

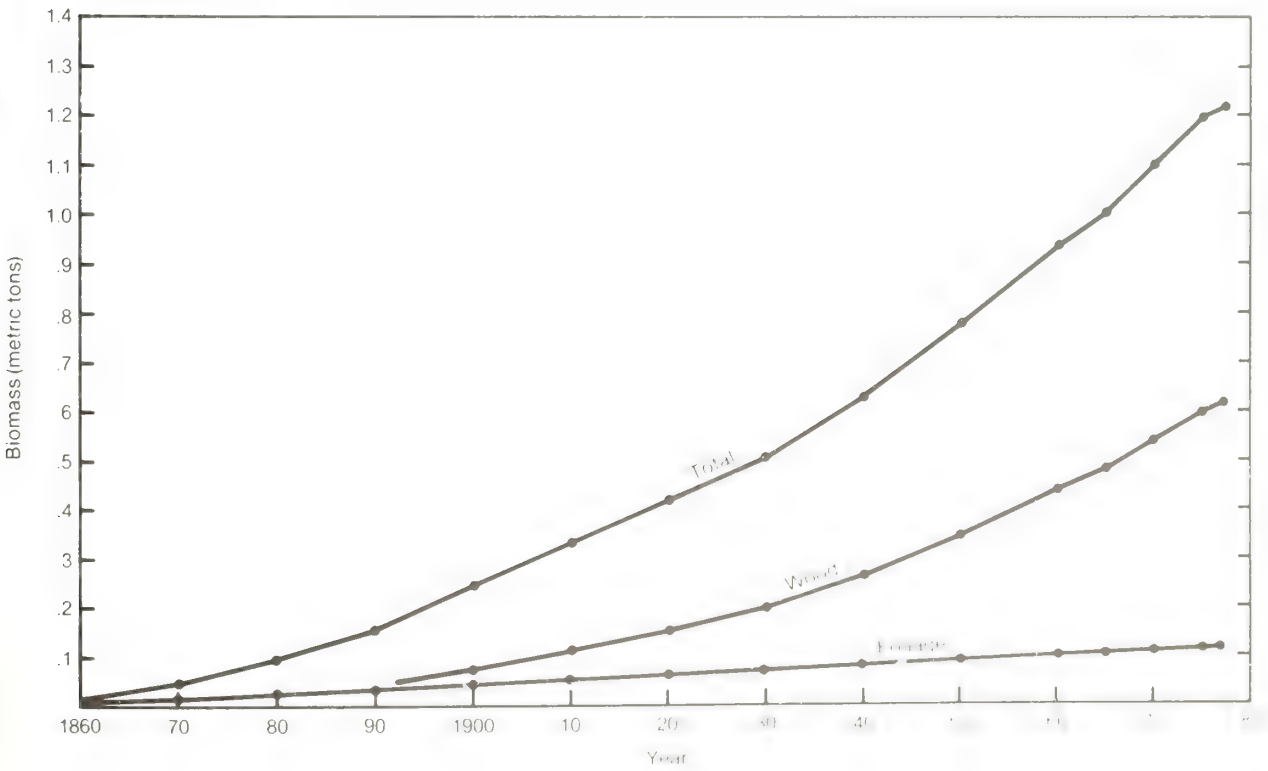


Figure 11.--Foliage, wood, and total above-stump biomasses of tree #31 on the Green Creek plot from 1860 to 1977. Foliage biomass is the ovendry mass of needles. Wood biomass is the ovendry mass of wood (bark excluded) larger than 76 mm diameter.

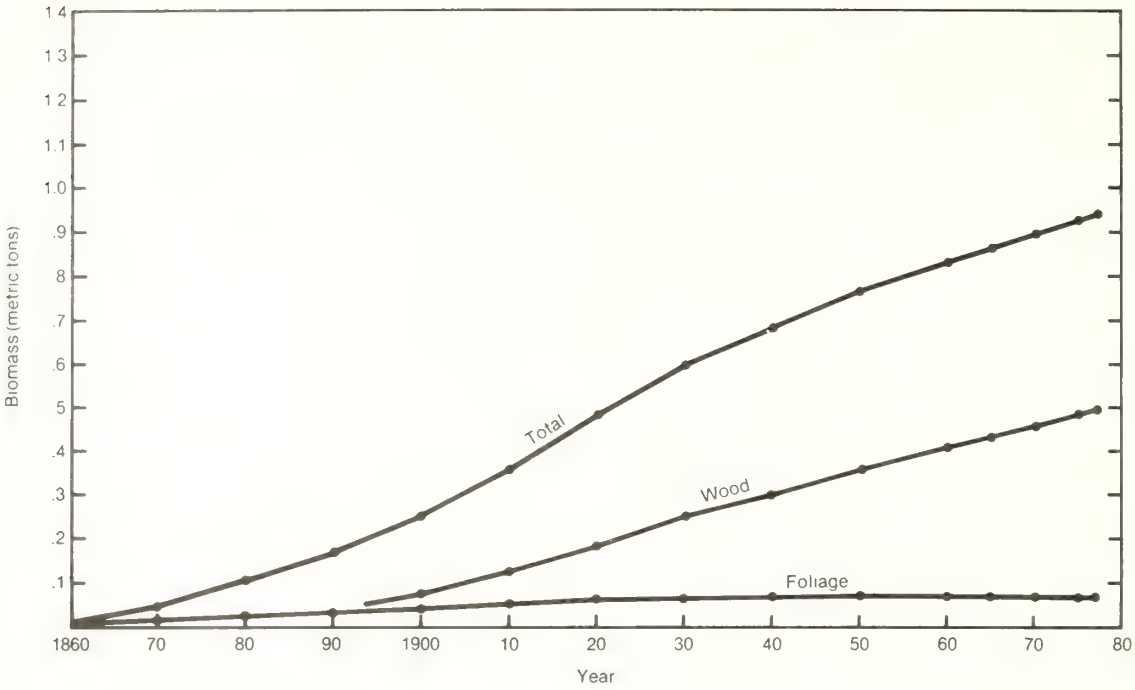


Figure 12.--Foliage, wood, and total above-stump biomasses of tree #29 on the Cattle Trough plot from 1860 to 1977. Foliage biomass is the ovendry mass of needles. Wood biomass is the ovendry mass of wood (bark excluded) larger than 76 mm diameter.

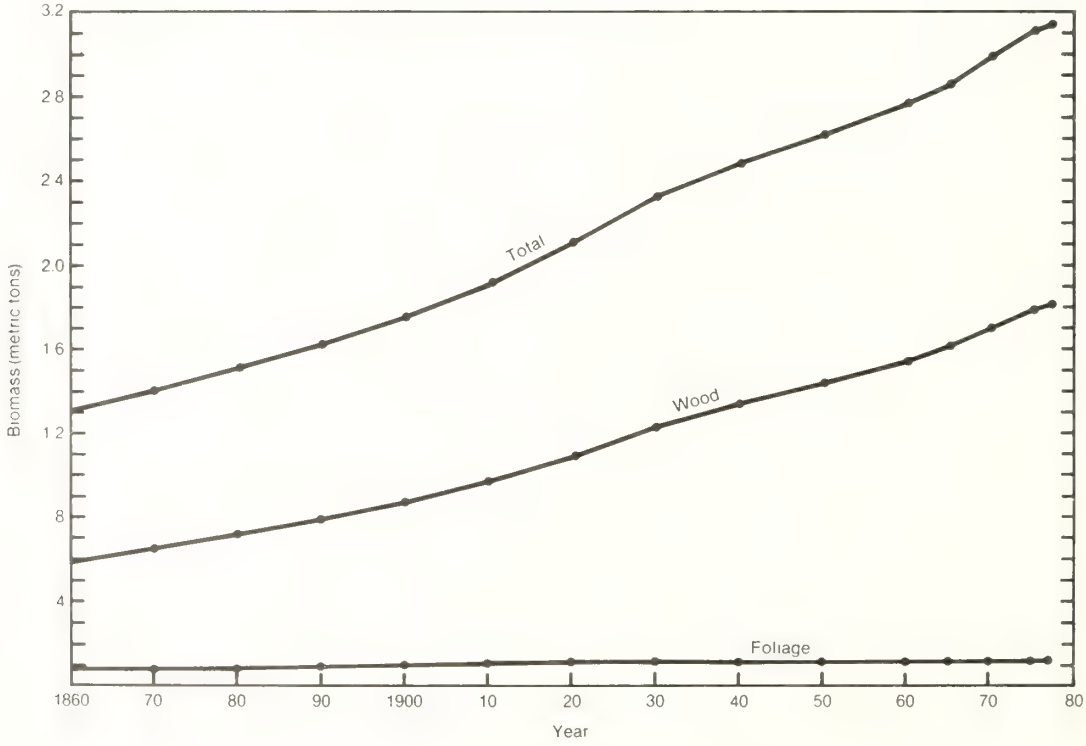


Figure 13.--Foliage, wood, and total above-stump biomasses of tree #31 on the Monte Cristo plot from 1860 to 1977. Foliage biomass is the ovendry mass of needles. Wood biomass is the ovendry mass of wood (bark excluded) larger than 76 mm diameter. This tree was estimated to be 433 years old in 1977.

On a stand basis, biomass growth follows trends similar to those of the individual large trees (figs. 14, 15, and 16). On the Green Creek plot (fig. 14), growth rates of all three components--foliage, wood, and total--continued to increase until 1975. As mentioned earlier, the slight decline in growth rates from 1975 to 1977 was probably due to the combined effects of the drought during that period and the measurement of the trees before current season growth was completed; the decline does not necessarily indicate a change in trend of growth rates.

In contrast, rates of biomass increment on the Cattle Trough plot (fig. 15) have been essentially constant since about 1920. The growth pattern on the Monte Cristo plot (fig. 16) is intermediate between the other two plots, although biomasses are greater. Growth rates at Monte Cristo were essentially constant from 1910 to 1950, but growth rates tended to increase from 1950 to the time the plot was measured.

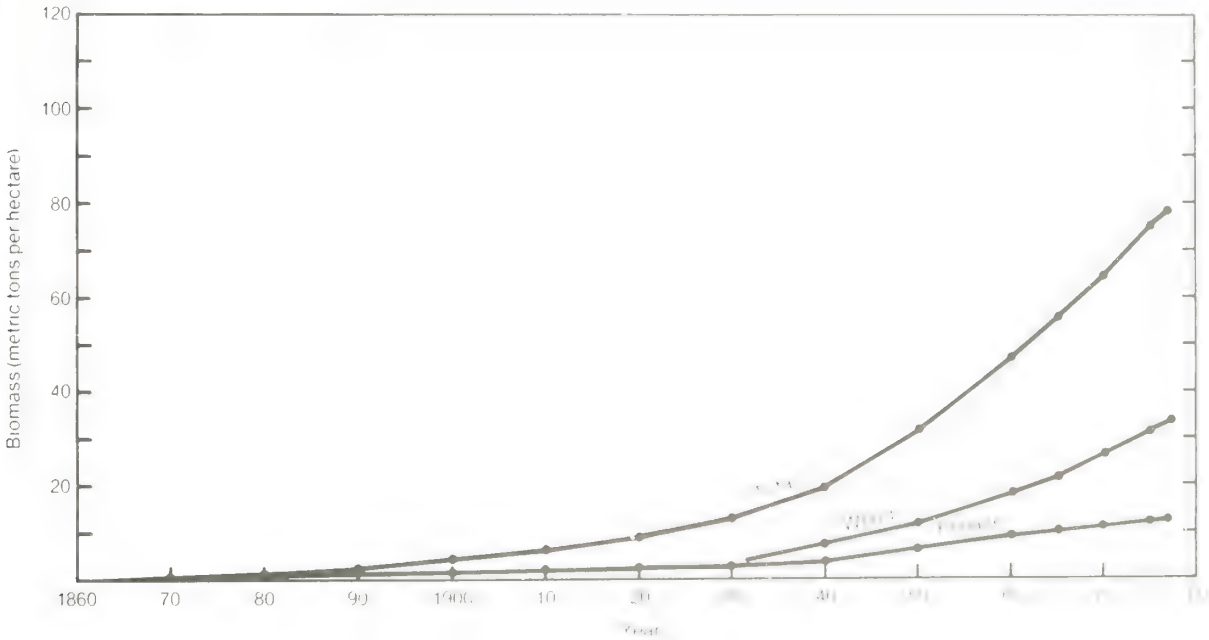


Figure 14.--Foliage, wood, and above-stump biomasses in metric tons per hectare on the Green Creek plot from 1860 to 1977.

The differences in growth patterns among these plots were caused mainly by differences in tree density and age structure. The Green Creek plot had a young stand, only five trees in the plot were more than 100 years old (table 2). The Cattle Trough plot had a dense stand essentially 80 years more advanced than Green Creek; 43 trees on this plot were more than 100 years old. The Monte Cristo plot had the greatest diversity of ages but, unlike Cattle Trough, the density was not great and many of the younger trees were not subject to competition from the older trees.

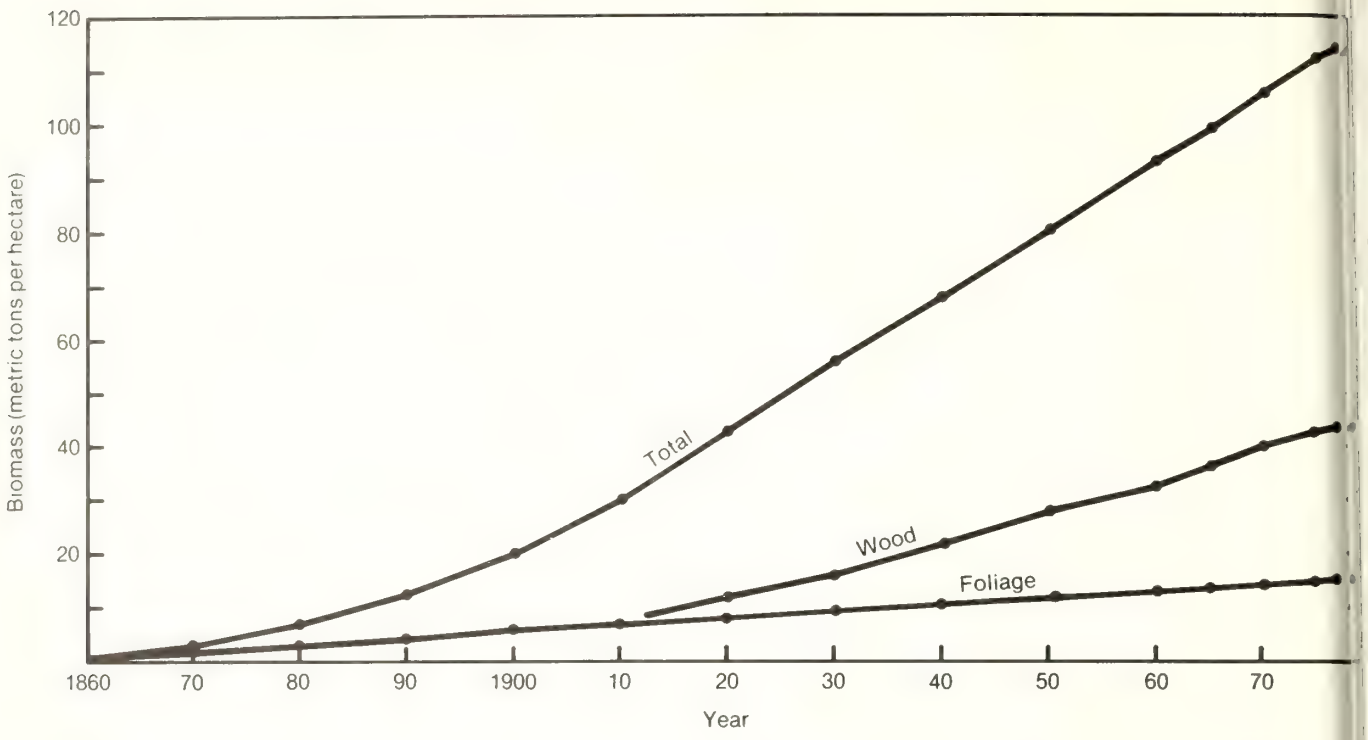


Figure 15.--Foliage, wood, and total above-stump biomasses in metric tons per hectare on the Cattle Trough plot from 1860 to 1977.

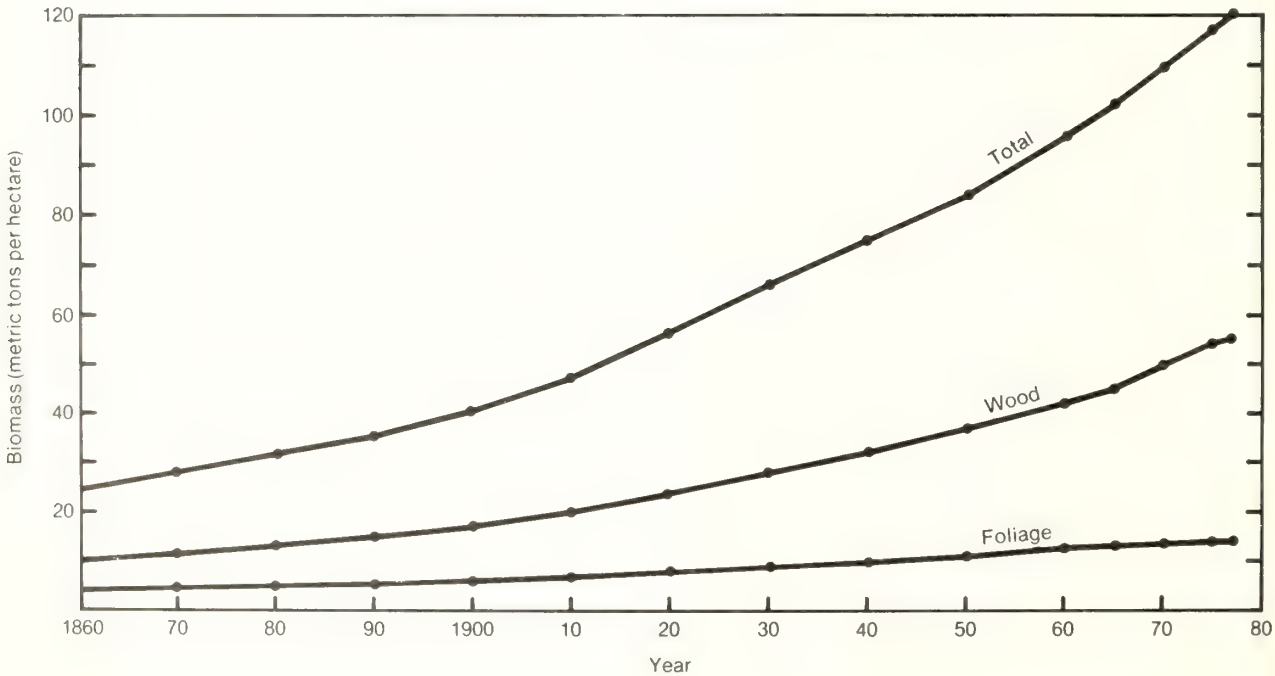


Figure 16.--Foliage, wood, and total above-stump biomasses in metric tons per hectare on the Monte Cristo plot from 1860 to 1977.

CONCLUSIONS

Since the data were obtained on only three plots in a single area and do not include juniper, the results obtained in the Sweetwater area may not apply to pinyon-juniper stands throughout the Great Basin. Pinyon-juniper stands in central and eastern Nevada will be examined in a similar manner to broaden the data base and extend the area of applicability. However, the Sweetwater results suggest a number of characteristics of singleleaf pinyon trees and stands that may be common throughout the range of this species with or without juniper association. These characteristics are as follows:

1. Height growth of dominants and codominants appears to be little affected by age or competition. Height growth rates of dominants and codominants generally remained constant during most of their lives; the only trees that were found to be approaching culmination of height growth were those trees that were severely suppressed.

2. Height growth rates can vary significantly among dominants on the same plot. Differences in height growth of dominants may be due to genetic variation. These differences appear to be linked to growth form; height growth is generally slower in trees that have a shrubby form and multiple leaders.

3. Diameter growth rate is regulated by competition rather than by age.

4. The rate of increase of stand basal area becomes relatively constant when the trees dominate the site. The rate of basal area increase of closed stands may be an accurate index of site potential, providing the stand is not decadent. Truly decadent stands are probably very rare in the pinyon-juniper type.

5. The increase in total above-ground biomass approaches a constant rate after the trees fully dominate the site. Eventually the rate of biomass increment must decrease but there was no indication of an impending decrease on the three plots in the Sweetwater study area. The rate was still increasing on two of the plots. Pinyon trees grow so slowly that maximum biomass may not be attained for several centuries. The data suggest that growth rate is essentially constant until the maximum biomass is approached.

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APPENDIX I — Regression Equations for Present Biomass

The following logarithmic equations were used to estimate foliage, wood, and total above-stump biomasses of all unweighed trees taller than 1 m on the Sweetwater plots:

$$(\ln F) = .486\ (\ln D) + .470\ (\ln H) + 1.287\ (\ln C_x) - .306\ (\ln D) \cdot (\ln C_x) - 1.560 \quad (3)$$

$$(\ln W) = 3.167\ (\ln D) + 2.827\ (\ln H) - .408\ (\ln D) \cdot (\ln H) + .120\ (\ln D) \cdot (\ln C_x) - 14.141 \quad (4)$$

$$(\ln M) = 2.416\ (\ln D) + .463\ (\ln H) + 1.776\ (\ln C_x) - .243\ (\ln D) \cdot (\ln C_x) - 8.429 \quad (5)$$

in which:

F = foliage biomass = ovendry mass of foliage (kg)
W = wood biomass = ovendry mass of wood (bark excluded) larger than 76 mm diameter (kg)
M = total above-stump biomass = total ovendry mass above a 15 cm stump (kg)
D = diameter of outside bark at stump height (cm)
H = total height of tree (dm)
C_x = maximum crown diameter (dm)
C^x = average crown diameter (dm)--the geometric mean of the maximum crown diameter and the crown diameter perpendicular to the maximum.
K = foliage class as defined in the methods section.

The coefficients of determination (R^2) are 0.936 for foliage, (eq. 3), 0.991 for wood (eq. 4), and 0.988 for total (eq. 5). The standard errors of estimate are 0.267, 0.163, and 0.148, respectively.

APPENDIX II — Regression Equations for Past Biomass

Diameter, height, and age can be used to estimate past biomass because they can be determined accurately for any time in the past. Crown parameters cannot be used as they were for present biomass, because their past values cannot be estimated accurately. The following equations were developed to estimate past biomass:

$$(\ln F) = 2.229\ (\ln D) + 1.027\ (\ln H) - .201\ (\ln H) \cdot (\ln T) - 4.406 \quad \text{(eq. 6)}$$

$$(\ln W) = 3.394\ (\ln D) + 2.433\ (\ln H) - .278\ (\ln D) \cdot (\ln H) - 13.521 \quad \text{(eq. 7)}$$

$$(\ln M) = 2.695\ (\ln D) + .670\ (\ln H) - .0806\ (\ln D) \cdot (\ln H) - 5.258 \quad \text{(eq. 8)}$$

The symbols are as defined in appendix I except for the introduction of T, the age (years) of the tree at stump height, in equation 6. The coefficients of determination (R^2), are 0.891 for foliage (eq. 6), 0.990 for wood (eq. 7), and 0.978 for total (eq. 8). The standard errors of estimate are 0.342, 0.173, and 0.205, respectively, and are substantially greater than their counterparts in appendix I.

The last term (the intercept) in the equations was not used in the calculation of past biomass. A new intercept was calculated for each equation and each tree such that biomass calculated for 1977 equals the measured biomass of weighed trees or the estimated biomass of unweighed trees as calculated by the equations in appendix I. For the foliage equation, for example, the proper intercept term (I) was calculated by:

$$I = (\ln F) - 2.229\ (\ln D) - 1.027\ (\ln H) + .201\ (\ln H) \cdot (\ln T) \quad \text{(eq. 9)}$$

in which D, H, and T are 1977 values for diameter, height, and age of a particular tree; and F is foliage biomass, either weighed or calculated by eq. 3.

APPENDIX III — Tree Data

The measured and calculated data for the trees taller than 1 m on the three plots are in tables 3, 4, and 5. Diameter was measured by diameter tape outside bark at stump height (15 cm). The second column under crown diameter (min) is crown diameter perpendicular to maximum crown diameter. Age is total age, estimated by extrapolating the height-age curves to the ground surface. The biomasses in the next three columns were measured directly for the weighed trees. The regression equations in appendix I were used to calculate the biomasses of unweighed trees. A zero in these columns indicates a measured or calculated mass less than 0.5 kg. The last column is decadal diameter growth (bark included) for the years 1966 through 1975.

Table 3.--*Dimensions, foliage classes, ages, biomasses, and diameter growth rates of pinyons on the Green Creek plot*

Tree number	Stump diameter	Height	Crown diameter Max.	Crown diameter Min.	Foliage class[1]	Age	Biomass Foliage	Biomass Wood	Biomass Total	Diameter growth
	cm	*dm*	*dm*			*years*	*kg*			*mm/10 yrs*
1	18	30	24	20	2	64	6	6	34	41
2	21	60	48	32	3	64	21	30	125	34
3	22	59	41	27	3	65	17	30	113	34
4	24	52	40	30	3	69	18	29	119	27
5[2]	6	21	16	14	2	57	1	0	3	20
6	46	72	60	38	5	82	54	193	523	66
7	17	67	40	30	3	65	17	22	79	27
8	21	60	38	35	5	69	24	27	98	30
9	11	39	14	10	2	63	2	3	9	23
10	5	18	14	10	2	83	1	0	2	5
11	29	74	63	40	5	86	46	85	288	38
12	34	69	58	50	5	87	53	101	324	36
13	26	54	40	38	6	69	29	36	137	40
14	42	74	58	49	5	150	60	165	452	35
15	14	42	23	21	2	84	6	6	25	27
16	33	76	50	42	4	92	41	102	283	29
17	46	79	84	82	6	115	122	253	726	38
18	21	63	21	20	2	81	8	24	54	20
19	5	30	5	5	1	62	0	0	0	6
20	22	62	38	34	4	78	22	32	107	59
21[2]	34	69	54	50	6	79	78	126	399	51
22	14	20	20	16	3	39	4	1	15	32
23	29	53	37	34	5	72	25	42	148	43
24	16	30	28	24	2	66	7	5	34	31
25[2]	14	42	27	17	5	60	4	6	24	38
26	27	62	47	30	3	78	23	51	180	44
27[2]	25	72	55	32	2	75	35	46	170	50
28	24	61	35	30	4	95	20	35	112	46
29	39	70	64	55	5	142	64	139	432	44
30	51	86	75	70	6	147	112	324	790	50
31[2]	59	96	93	66	3	195	119	615	1,212	37
32[2]	15	32	21	17	5	81	5	3	20	23
33	4	11	10	8	2	40	0	0	0	16
34	23	40	20	7	2	62	3	14	49	47
35[2]	14	34	20	19	3	74	4	3	17	41

[1]Foliage class estimated on a scale of 1 to 9; 1 = very sparse foliage, 9 = dense foliage on all sides.

[2]Indicates trees that were actually weighed.

Table 1.--

Tree number	Stump diameter	Height	Crown diameter: Max.	Crown diameter: Min.	Foliage class[1]	Age				
1	24	52	30	15	3	45				16
2	4	11	9	9	2	50	6		1	3
3	11	30	23	22	4	86	6			
4	42	78	61	40	3	177	64	181	1	7
5	25	86	36	20	3	177	17		144	
6	22	78	41	33	1	141		15	1	11
7	20	15	25	19	4	148	6			
8	24	56	32	30	3	1	16	2		21
9	6	13	10	6	2	80	1		1	
10	26	60	49	16	5	118	1	16	1	
11	38	84	60	43	5	129	57	165	428	21
12	43	85	78	48	3	165	77	236	1	12
13	3	10	7	4	1	78				3
14	26	93	30	18	4	138	17	73	1	13
15	31	71	70	42	5	147	32	95	343	13
16	25	68	43	37	4	1	33	49	154	2
17	22	73	31	21	4	147	10	39	1	12
18	22	69	23	20	3	171	11	31	67	4
19	20	52	31	23	4	163	18	18	69	11
20	44	94	50	48	5	191	61	230	475	15
21	11	22	27	20	4	73	6	1	15	9
22	20	46	20	18	4	111	8	13	31	26
23	12	43	16	14	3	80	1	4	1	19
24	22	57	31	23	4	107	15	26	84	18
25	22	52	34	32	5	139	20	23	88	12
26	35	87	51	38	5	170	46	134	334	8
27	13	46	21	17	4	81	2	6	21	19
28	40	64	81	62	7	148	90	144	529	7
29[2]	59	97	69	60	7	158	73	500	947	17
30	22	54	35	23	4	151	15	25	91	6
31[2]	31	92	25	23	3	146	15	96	192	11
32[2]	40	102	41	34	4	168	29	236	496	11
33	30	66	43	39	4	169	1	60	1	11
34	38	71	47	43	6	164	18	118	1	17
35	10	30	16	9	3	110	2	1	1	2
36	32	56	36	32	5	82	26	55	1	29
37	5	32	11	6	3	67	1	1	1	15
38	5	22	9	9	3	55	1	1	1	7
39	18	55	34	28	5	73	17	17	66	30
40	31	66	56	55	5	154	51	78	269	7
41	35	85	52	45	4	143	47	135	536	1
42[2]	9	36	18	11	3	115	2	1	3	1
43[2]	19	78	30	22	3	154	6	28	78	14
44	30	88	46	41	5	152	42	140	243	1
45	26	88	45	36	3	151	29	78	192	1
46	6	27	5	5	4	114	1	0	1	11
47	32	87	56	55	4	168	1	122	20	1
48	18	52	26	23	5	79	1	11	48	28
49	9	12	6	5	2	79	1	1	3	1
50	8	29	18	13	3	68	3	1	6	1
51	9	45	10	7	4	84	2	1	3	11
52	29	84	40	38	5	104	35	98	200	24
53	10	35	22	21	5	71	7	1	1	1
54	16	33	29	26	4	86	4	5	36	14
55	19	64	27	23	5	101	12	3	60	26
56	5	21	10	10	4	69	1	10	1	12
57	18	67	24	20	4	100	11	21	50	27
58	24	30	41	25	4	134	4	10	100	6
59	2	13	7	6	2	68	0	0	0	1
60	12	15	22	17	4	61	6	1	1	26
61	29	92	53	32	4	130	1	1	11	3
62	27	78	29	21	3	149	15	10	125	1
63	39	96	74	45	5	143	2	226	1	1
64	3	11	6	5	2	48	0	0	0	1

[1]Foliage class estimated on a scale of 1 to 9; 1 foliage on all sides.

[2]Indicates trees that were actually weighed.

Table 5.--*Dimensions, foliage classes, ages, biomasses, and diameter growth rates of pinyons on the Monte Cristo plot*

Tree number	Stump diameter	Height	Crown diameter		Foliage class[1]	Age	Biomass			Diameter growth
			Max.	Min.			Foliage	Wood	Total	
	cm	*dm*	*dm*			*years*	*kg*			*mm/10 yrs*
1[2]	32	79	47	36	5	78	43	81	238	59
2	26	66	45	36	5	100	31	51	168	25
3[2]	12	42	21	19	3	75	8	5	23	32
4	41	74	61	49	6	125	66	162	456	21
5[2]	6	24	16	10	3	48	1	0	3	21
6[2]	40	75	56	39	3	128	42	160	367	19
7[2]	35	64	45	34	3	109	27	76	225	21
8	27	52	35	34	2	86	16	35	125	36
9	18	64	27	22	5	78	14	20	55	37
10	29	72	62	40	5	78	45	81	280	32
11	28	57	56	32	4	101	30	52	217	22
12	18	41	19	10	1	78	3	9	31	12
13	10	39	18	15	3	4	4	2	10	19
14[2]	6	21	14	12	3	64	1	0	3	20
15[2]	22	62	35	27	3	112	9	31	82	22
16	26	61	40	36	3	85	23	43	145	27
17	7	26	20	8	2	76	2	1	5	21
18	24	55	45	35	6	80	29	33	137	41
19	22	61	42	25	5	108	21	31	112	16
20	16	38	20	12	4	69	5	6	26	25
21	10	23	15	10	3	62	2	1	7	18
22	37	77	65	55	5	140	66	144	426	24
23	9	34	14	13	3	76	3	1	6	15
24[2]	72	104	112	79	3	259	140	840	1,636	25
25	9	34	14	10	4	71	3	1	6	15
26	28	68	35	26	3	159	19	55	150	9
27	44	64	58	50	4	160	53	150	452	14
28	9	28	24	15	3	74	4	1	11	21
29	61	109	92	88	7	242	193	657	1,319	20
30	28	83	40	35	6	165	35	78	187	17
31[2]	104	101	129	114	1	433	136	1,821	3,137	33
32	24	41	36	32	6	70	21	19	96	41
33	21	57	30	25	5	94	16	23	75	28
34	43	96	72	48	3	251	158	267	635	9

[1]Foliage class estimated on a scale of 1 to 9; 1 = very sparse foliage, 9 = dense foliage on all sides.

[2]Indicates trees that were actually weighed.

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Meeuwig, Richard O., and Jerry D. Budy.
1979. Pinyon growth characteristics in the Sweetwater Mountains. USDA For. Serv. Res. Pap. INT-227, 26 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Stem analyses of singleleaf pinyon (Pinus monophylla) indicate that height growth rates vary considerably among dominants on the same site but that the rate of height growth of each tree tends to be constant throughout most of its life, regardless of age or competition. Radial growth rates are sensitive to competition but appear to be unaffected by age. Stand basal area increment and biomass accumulation rates tend to be constant in fully-stocked stands.

KEYWORDS: singleleaf pinyon, biomass, Pinus monophylla, silvics

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GROSS CUBIC-VOLUME EQUATIONS AND TABLES, OUTSIDE BARK, FOR PINYON AND JUNIPER TREES IN NORTHERN NEW MEXICO

Gary W. Clendenen

SEP

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RESEARCH SUMMARY

Presents cubic-volume equations and tables for estimating gross cubic volume outside bark of individual pinyon and juniper trees in northern New Mexico; also shows procedures used in building mathematical models.

GROSS CUBIC-VOLUME EQUATIONS . . . FOR PINYON AND JUNIPER TREES IN NORTHERN NEW MEXICO

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

CONTENTS

	Page
INTRODUCTION	1
DATA COLLECTION	1
DATA ANALYSIS	1
RESULTS	5
APPLICATION	9
CONCLUSIONS	10
PUBLICATIONS CITED	11
APPENDIX I (Subroutines)	13
APPENDIX II (Tables)	15

INTRODUCTION

Pinyon and juniper trees are commonly small and scrubby, have rapid taper and a bushy appearance. These characteristics, which are different from those of tree species conventionally managed for production of sawlogs, give both the private landowner and the public forester some unusual problems in estimating wood volume. Few volume tables have ever been published, and volume equations are virtually nonexistent. Howell and Lexen published some tables in the late 1930's and early 1940's (Howell and Lexen 1939; Howell 1940 and 1941) and Moessner later published an aerial photo volume table (1962). All these tables were published within one cover by Barger and Ffolliot (1972).

DATA COLLECTION

The lack of adequate equations or tables for estimating cubic volumes of pinyon and juniper plus the interest of personnel on the Carson National Forest in New Mexico in assessing the current situation in their pinyon and juniper resources resulted in plans for a cooperative study. Participants were the Intermountain Forest and Range Experiment Station's Renewable Resources Evaluation work unit, the Carson National Forest, and the Southwestern Region of the Forest Service. The data used to develop the cubic volume equations presented here were collected on the Carson National Forest as part of this cooperative study. Independent variables collected and used in the data analysis were:

1. Species
2. Basal diameter outside bark--diameter at ground line
3. Total tree height
4. Number of 3-in (7.62 cm) and larger forks anywhere on the stem where both stems coming out of the fork were 3 in or larger diameter outside the bark
5. Number of stems 3-in (7.62 cm) diameter and larger outside the bark and originating within the first 12 in (30.43 cm) above ground line.

The two independent variables measured for use in determining cubic-foot volume of each sample tree were: (1) the number of segments in each tree by 2-ft (0.61 m) length classes, and (2) 2-in (5.08 cm) midpoint diameter classes (2 to 8 ft, or 0.61 to 2.44 m). The midpoint diameter classes were even 2-in (5.08 cm) classes; 2-in (5.08 cm) diameters were the smallest. If any segment (except for the 2-ft length class) had more than 2 in of taper, it was divided into two or more segments such that maximum taper within a segment could not exceed 2 in (5.08 cm).

Of the several species of pinyons and junipers native to the Rocky Mountain West, only three were encountered in this study: pinyon (*Pinus edulis* Engelm.) and Rocky Mountain and Utah junipers (*Juniperus scopulorum* Sarg. and *J. osteosperma* [Torr.] Little). Of the total of 2,318 trees measured, 1,559 were pinyons and 759 were junipers. The trees were selected from 96 field plots randomly scattered about the Carson National Forest.

DATA ANALYSIS

Using diameter and length class, the cubic volume was calculated for each segment in each sample tree assuming the segment was a cylinder having diameter equal to the segment midpoint diameter and length equal to the segment length class (Huber's formula).

The segment cubic volumes were then summarized by diameter [illegible] cubic volume for each tree by six different top diameters--1 in through 11+ in (2.54 cm-27.94 cm) by 2-in (approximately 5 cm) odd increments. Cubic volume, so calculated, was used as the dependent variable for regression analyses.

A combinatorial screening approach (Grosenbaugh 1967) was used initially to determine which combination of pertinent transforms of all independent variables gave the best estimate of cubic volume. The results indicated basal diameter and total height to be the best predictors of cubic volume for pinyon. Basal diameter, height, and number of forks provided the "best" correlation with juniper volume. Substituting number of stems for number of forks gave a slightly smaller correlation; however, number of stems was selected for the final juniper volume model because number of stems is more easily and accurately determined in the field.

After these independent variables were selected, the data were summarized by species for each minimum top diameter limit. For pinyon, mean cubic volume was computed for each 2-in (approximately 5 cm) basal diameter class and each 5-ft (1.5 m) height class. For juniper, mean cubic volume was computed for each 2-in (5 cm) basal diameter class, 5-ft (1.5 m) height class, and number-of-stems class. These mean cubic volumes were then used to develop a refined volume model that was finally fitted to all individual tree volumes by linear least squares techniques.

The following constraints were applied to the volume models:

1. Volume should increase over height and must pass through zero cubic volume when height equals zero.

2. Volume should increase over basal diameter and must pass through zero cubic volume when basal diameter equals minimum top diameter limit.

3. Volume must approach zero cubic volume as number of stems increases.

4. Volume must decrease with increasing minimum top diameter limit.

5. The minimum top diameter components must not cross.

6. The number of stem components of model must not cross.

An initial plotting of the data indicated volume increased linearly over height and was concave upward over basal diameter.

The first constraint is satisfied by a model of the form $Y = bH$ where b is expressed as a function of basal diameter, number of stems, and minimum top diameter limit. Minimum top diameter limits of 9 in (22.86 cm) and 11 in (27.94 cm) were dropped from the analysis because inadequate sample sizes resulted in inconsistent trends. The final model was then developed using minimum top diameter limits of 1, 3, 5, and 7 in (2.54, 7.62, 12.70, and 17.78 cm).

The first step in the model building process was to fit a weighted linear equation of the basic model form through the origin with height as the independent variable and cubic volume as the dependent variable. This was done for each species, 2-in (5 cm) basal diameter class, minimum top diameter limit, and in the case of juniper, each number-of-stem class up to six. Beyond six stems, the data base was insufficient to determine consistent trends. The weights used were the number of observations contributing to each mean volume.

Next, the resulting slopes (b coefficients) were plotted over basal diameter minus minimum top diameter limit. Basal diameter minus minimum top diameter limit was used because of the second constraint mentioned previously. Matchacurve techniques (Jensen 1964, Jensen and Homeyer 1970, 1971, Jensen 1973, 1976) were used to describe the trends of the slopes in relation to basal diameter minus minimum top diameter for each minimum top diameter class. For pinyon, the power function of the form

$$\hat{Y} = aX^n$$

was a satisfactory descriptor with a and n to be a function of minimum top diameter alone. For juniper, a single power function did not provide enough upward curvature for the larger basal diameters; therefore, a multiple component model having the following form was used:

$$\hat{Y} = a_1 X^{n_1} + a_2 X^{n_2}$$

where the $a_2 X^{n_2}$ component becomes essentially zero for small diameters.

As in step 1, each model component was fitted through the origin by weighted (number of observations) least squares techniques.

For juniper, the slopes were also a function of number of stems. The number-of-stems effect was allowed to asymptote toward zero at 20 stems.

Appropriate power functions for the minimum top diameter limit effect were then determined. The same procedure as used in step 2 was employed, except this time the independent variable was minimum top diameter limit.

The components were combined for each model and the latter were each fitted to their respective data set by least squares techniques. The simple linear model, $\hat{Y} = b\ (model)$, was used, forcing the model through the origin. The resulting coefficients were very close to 1, indicating that the models as developed fitted the overall data trends very well.

Next the residuals were plotted over estimated volume. The plotted residuals showed increasing residuals with increasing estimated volume, indicating a need to weight the estimate of b in the final models. Draper and Smith (1966) and Cunia (1964) recommend weighting the dependent variable by the reciprocal of the variance where variance is unequal. An estimate of the variance can be obtained from the residuals squared.

The next step was to screen possible variables for correlation with residuals squared. The LOG of the residuals squared was screened against all possible combinations of the LOG's of the following variables:

1. Estimated cubic volume
2. Basal diameter minus minimum top diameter limit
3. Minimum top diameter limit
4. Height
5. Number of stems (juniper only).

The screen indicated the estimated cubic volume was the simplest, best overall predictor of residuals squared.

A LOG model of the following form was fitted to the [illegible] of variance as a function of estimated cubic volume:

where:

$(Y - \hat{Y})^2$ = estimated variance, residuals squared
Y = field measured cubic volume
$\hat{Y}$ = estimated cubic volume from previous regression.

Substituting V for $(Y - \hat{Y})^2$ and taking the antilog yielded:

Therefore, the estimated weight was:

Since a is a constant, it was dropped from the weight without affecting the relationship between the weights over estimated cubic volume. Dropping the constant yielded:

After the initial estimate of the weight was determined, the model was fitted using weighted least squares techniques. From the weighted model, a new estimate of [illegible] and corresponding weight was obtained by again fitting a LOG model. Having obtained a new b value for the estimated weight, a new weighted regression was computed. The fourth iteration of this process yielded weights and regression coefficients essentially the same as the third iteration; this indicated the weights had stabilized and an appropriate weight had been found. The final weight used for the weighted regression was:

$$w = \frac{1}{\hat{Y}^b}$$

where:

$\hat{Y}$ = estimated cubic volume from previous iteration
b = 1.43 for pinyon and 1.40 for juniper

Next another plot of the residuals was made over estimated cubic volume. The residuals were weighted by the square root of the weight used for the final weighted regression. The plot showed that the residuals:

1. Appeared in a horizontal band
2. Appeared balanced overall
3. Appeared unbalanced close to the origin
4. Appeared unbalanced for large estimated cubic volumes
5. For juniper only, had a conspicuous absence of positive residuals at 1.4 ft (0.42 m) offset by an absence of negative residuals at 25 ft (0.71 m).

Items 1 and 2 indicate appropriate weights were used. Items 3 and 4 indicate an intercept value should be included in the model. Item 5 indicates that two segments of the juniper model do not fit the data trends, but the lack of fit in one segment is offset by a corresponding lack of fit in another. Another examination of the means used to derive the original model revealed that to correct for the lack of fit in the two areas would result in an unrealistic model form. Therefore, the original model form was retained.

As a result of items 3 and 4, a new weighted regression was computed, this time with an intercept. The resulting intercepts were small [0.03 ft^3 (0.0008 m^3) for both pinyon and juniper], and the slope corrections were not unreasonable. A plot of the weighted residuals about the models with intercepts revealed that items 1 and 2 had been unchanged, items 3 and 4 had been corrected, and item 5 for juniper had been improved. Therefore, the weighted models with intercept values were accepted as the best linear unbiased estimators of cubic volume.

RESULTS

The final equations which follow have the following use restrictions:

1. The minimum top diameter limits must be in the range of 1 to 7 in (2.5 to 17.8 cm).

2. The number of stems cannot exceed 20.

3. The cubic volume predicted is total volume from ground line to point of minimum top diameter including bark and limbs.

4. The equations are considered representative of pinyon, Utah juniper, and Rocky Mountain juniper in northern New Mexico. Use elsewhere should be accompanied by suitable checks of applicability.

The pinyon cubic volume equation is:

$$V = c + bX^{n}H$$

where:

c (English units) = 0.02768

c (metric units) = 0.0007838

X (English units) = $D - TD$

X (metric units) = $\frac{D - TD}{2.54}$

D = basal diameter (at ground line) in inches for English units or centimeters for metric units

H = total tree height in feet for English units or meters for metric units

TD = minimum top diameter limit in inches for English units or centimeters for metric units

b (English units) = $0.08789 - 0.03675(11.0 - TD)^{0.35}$

b (metric units) = $0.0081652 - 0.0024637(27.94 - TD)^{0.35}$

n (English units) = $1.1 + 0.007(11.0 - TD)^{2.0}$

n (metric units) = $1.1 + 0.001085(27.94 - TD)^{2.0}$

V = gross cubic volume outside bark to the specified minimum top diameter limit including stump and limbs in cubic feet for English units or cubic meters for metric units.

Figure 1 illustrates the [illegible] means used for model development plotted and connected to the surface by a vertical line. Note that [illegible] diameter.

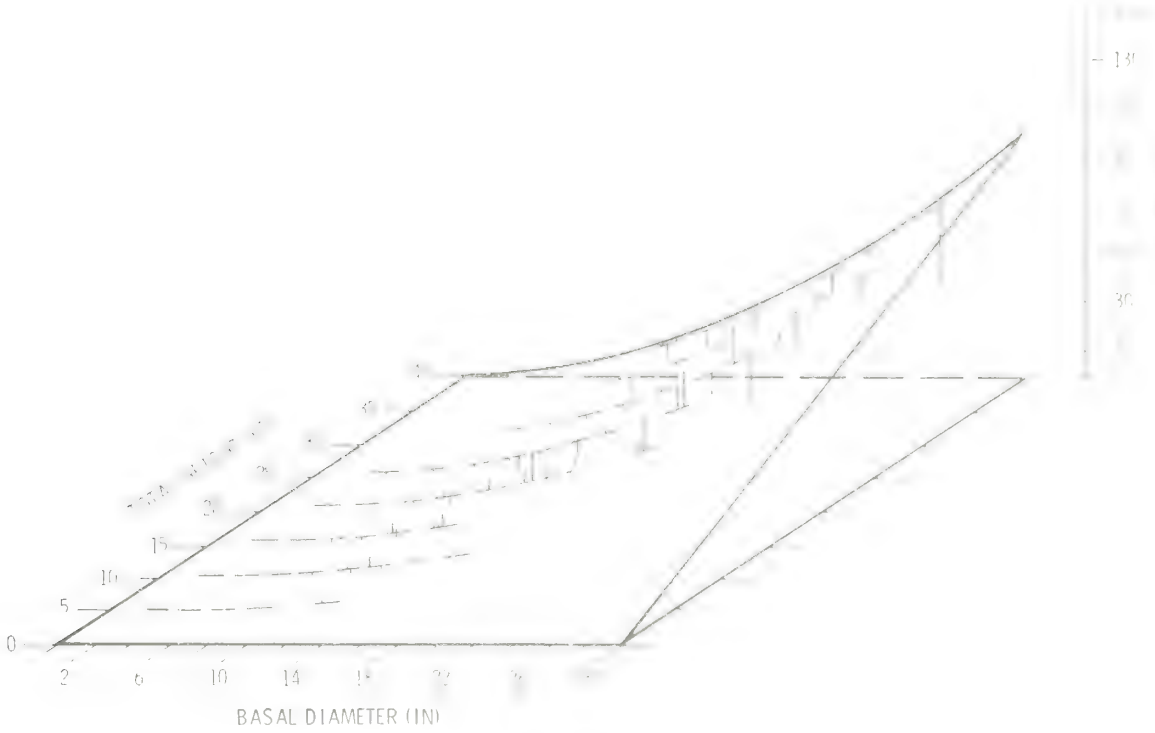

Figure 1.--[illegible] 1-inch minimum top diameter limit showing differences between [illegible] and corresponding predicted values.

The juniper cubic volume equation is

[illegible]

where:

c (English units) = 0.03066

c (metric units) = 0.0008682

$$r = \frac{20.0 - \text{STEMS}}{19.0}$$

n (English units) = $2.25 + 0.38130(TD - 1.0)$

n (metric units) = $2.25 + 0.15012(TD - 2.54)$

X (English units) = $0.00491(D - TD)^{1.8} + 1.501475\text{-}08$ [illegible]

X (metric units) [illegible]

STEMS = number of stems 3 in (7.62 cm) diameter and larger originating within first 12 in (0.3 m) above ground line. Trees less than 3 in (7.62 cm) basal diameter are considered single stemmed.

b (English units) = 1.08100 + 0.06263(TD - 1.0)

b (metric units) = 1.08100 + 0.0246575(TD - 2.54)

D = basal diameter (at ground line) in inches for English units or centimeters metric units

H = total tree height in feet for English units or meters for metric units

TD = minimum top diameter limit in inches for English units or centimeters for metric units

V = gross cubic volume outside bark to the specified minimum top diameter limit including stump and limbs in cubic feet for English units or cubic meters for metric units.

Figure 2 illustrates the juniper 1-in top diameter volume surface for single-stemmed trees showing the means used for model development plotted and connected to the surface by a vertical line. Note that more than 90 percent of the total data set was less than 14 inches basal diameter.

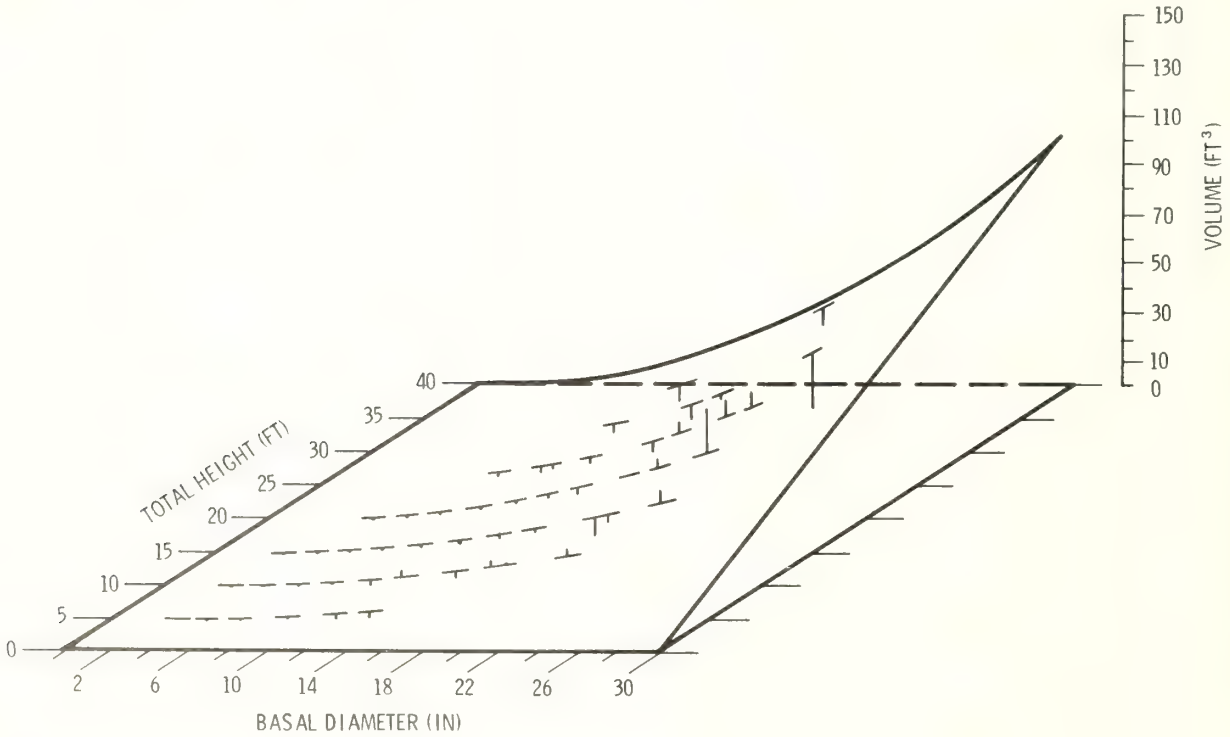

Figure 2.--Juniper gross-cubic volume outside bark including stump and limbs to 1-inch minimum top diameter limit for single stemmed trees showing differences between observation means and corresponding predicted values.

Figure 3 illustrates the top diameter effect for pinyon, and figure 4 illustrates the top diameter effect for single-stemmed juniper. Figure 5 illustrates the number-of-stems effect for juniper to a 1-in top diameter.

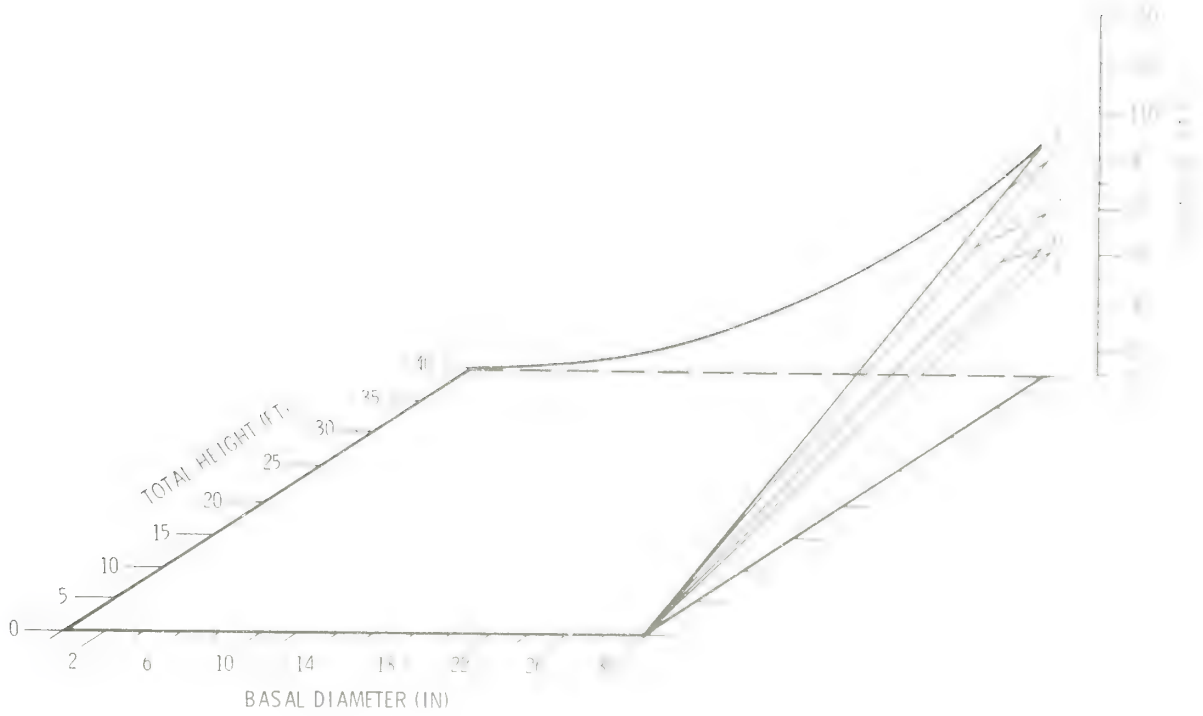

Figure 3.--Pinyon gross cubic-foot volume outside bark including stump and limbs to 1-inch, 2-inch, 4-inch, 6-inch, and 7-inch top diameter limits.

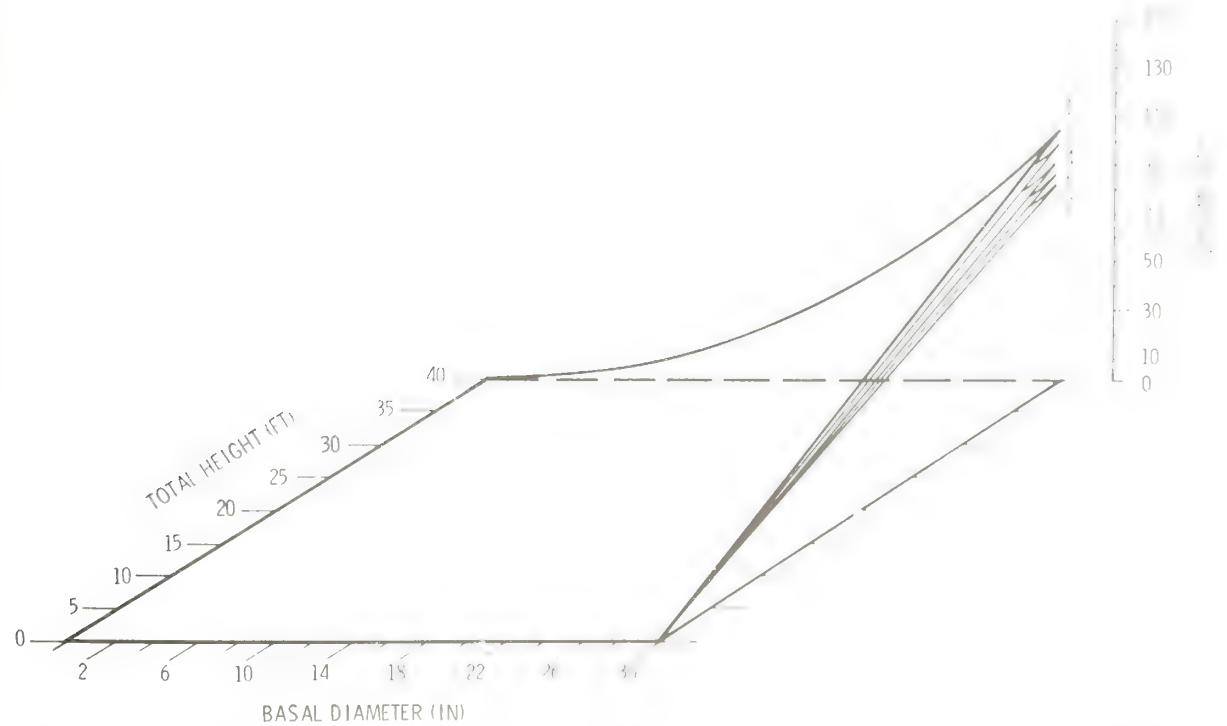

Figure 4.--Juniper gross cubic-foot volume outside bark including stump and limbs to 1-inch, 2-inch, 4-inch, and 7-inch minimum top diameter limits for single-stemmed trees.

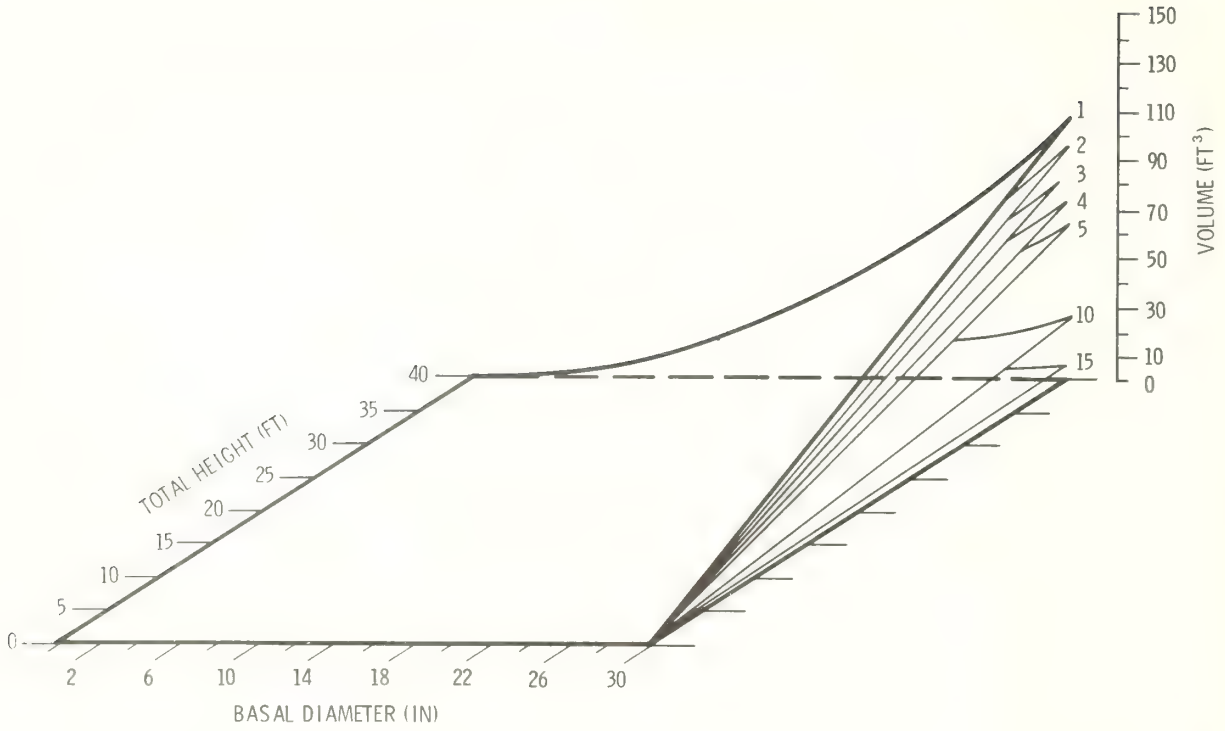

Figure 5.--Juniper gross cubic-foot volume outside bark including stump and limbs to 1-inch minimum top diameter for 1, 2, 3, 4, 5, 10, and 15 stemmed trees.

APPLICATION

The volume equations presented here are too complex to be solved easily with a desk calculator; therefore, two computer subroutines for computing individual tree volumes were written (English and metric units) and are included in Appendix I. The subroutines compute volumes in cubic feet with English unit input and cubic meters with metric unit input.

For desk calculator computation of tree volumes, tables 1 through 10 (in Appendix II) can be used. Tables 1 and 3 are in English units for pinyon and tables 5, 7, and 9 are in English units for juniper. Tables 2 and 4 are in metric units for pinyon and tables 6, 8, and 10 are in metric units for juniper.

To compute cubic-foot volume for a pinyon tree, first find the volume to a 1-in minimum top diameter for the tree in table 1. Then in table 3 find the appropriate proportion for the basal diameter of the tree and the desired minimum top diameter limit. Multiply the table 1 value by the table 3 value to obtain the cubic-foot volume of the tree to the desired minimum top diameter limit. Metric volume is obtained by the same procedure except that tables 2 and 4 are used instead of tables 1 and 3.

To compute cubic-foot [illegible] stemmed tree to a 1-in [illegible] appropriate proportion for the basal diameter of the tree and the desired minimum top diameter limit. Finally, [illegible] stems and the desired minimum top diameter limit. Multiply the values obtained from tables 5, 7, and [illegible] together [illegible] minimum top diameter limit. Metric volume is obtained by the same procedure except that tables 6, 8, and 10 are used instead of tables 5, 7, and 9.

Example: Assume a pinyon tree 10-in basal diameter and 30 ft tall. Determine the cubic-foot volume of this tree to a 4-in minimum top diameter limit. From table 1, the value 8.82 cubic feet is read. From table 4, the proportion 0.692 is read. The cubic-foot volume of this tree to a 4-in top is then 6.1 ft (8.82 X 0.692).

Example: Assume a juniper tree 12-in basal diameter, 20 ft tall, and having three stems originating within the first 12 in above ground line. Determine the cubic-foot volume of this tree to a 4-in minimum top diameter limit. From table 5,the value 8.034 is read. From table 7, the proportion 0.659 is read. From table 9, the proportion 0.686 is read. The cubic-foot volume of this tree to a 4-in top is then 3.63 ft (8.034 X 0.659 X 0.686).

CONCLUSIONS

The equations, computer subroutines, and tables presented in this paper are applicable throughout northern New Mexico for volume estimation in the pinyon-juniper type. Use outside of northern New Mexico should be accompanied by appropriate field checks.

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APPENDIX I

```
      SUBROUTINE PJVOL(BD,TD,STEMS,HT,ISPEC,V)
C
C     *****
C     *  THIS SUBROUTINE COMPUTES GROSS CUBIC-FOOT VOLUME FOR INDIVIDUAL
C     *  PINYON AND JUNIPER TREES.
C           REQUIRED INPUTS --
C     *         1.  DIAMETER AT GROUND LINE
C     *         2.  MINIMUM TOP DIAMETER LIMIT
C     *         3.  NUMBER OF 3-INCH AND LARGER STEMS ORIGINATING WITHIN
C     *              FIRST 12 INCHES ABOVE GROUND LINE FOR JUNIPER ONLY
C     *         4.  TOTAL TREE HEIGHT
C     *         5.  SPECIES INDEX OF 1 FOR PINYON AND 2 FOR JUNIPER
C     *****
C
      D = BD - TD
      IF(TD.LT.1.0.OR.TD.GT.7.0.OR.STEMS.LT.0.0.AND.ISPEC.EQ.2.OR.STEMS.
     1 GT.20.0.AND.ISPEC.EQ.2.OR.HT.LT.0.0.OR.D.LT.0) GO TO 20
      IF(ISPEC.EQ.2) GO TO 10
      IF(ISPEC.NE.1) RETURN
C
C     *****
C     * PINYON
C     *****
C
      V = (.08789 - .03675 * (11. - TD)**.35) * (D**(1.1 + .007 * (11. -
     1 TD)**2.0)) * HT + .02768
      RETURN
C
C     *****
C     * JUNIPER
C     *****
C
   10 IF(STEMS.LE.1.0) STEMS = 1.000000
      V = (((20. - STEMS) / 19.)**(2.25 + .3813 * (TD - 1.)) * (1.08100 +
     1  .06263 * (TD - 1.)) * ((.00491 * D**1.8) + (1.50147E-08 * D
     2 ** 5.0))) * HT + .030664
      RETURN
   20 V = 0.0
      RETURN
      END
```

```
      SUBROUTINE PJVOL(BD,TD,STEMS,HT,ISPEC,V)
C
C     *****
C     *  THIS SUBROUTINE COMPUTES GROSS CUBIC-METER VOLUME FOR INDIVIDUAL
C     *  PINYON AND JUNIPER TREES.
C     *     REQUIRED INPUTS --
C     *          1.  DIAMETER AT GROUND LINE
C     *          2.  MINIMUM TOP DIAMETER LIMIT
C     *          3.  NUMBER OF 3-INCH AND LARGER STEMS ORIGINATING WITHIN
C     *               FIRST 12 INCHES ABOVE GROUND LINE FOR JUNIPER ONLY
C     *          4.  TOTAL TREE HEIGHT
C     *          5.  SPECIES INDEX OF 1 FOR PINYON AND 2 FOR JUNIPER
C     *****
C
      D = (BD - TD) / 2.54
      IF(ISPEC.EQ.2) D = D * 2.54
      IF(TD.LT.2.5.OR.TD.GT.15..OR.STEMS.LT.0.0.AND.ISPEC.EQ.2.OR.STEMS.
     1 GT.20.0.AND.ISPEC.EQ.2.OR.HT.LT.0.0.OR.D.LT.0) GO TO 20
      IF(ISPEC.EQ.2) GO TO 10
      IF(ISPEC.NE.1) RETURN
C
C     *****
C     * PINYON
C     *****
C
      V = (.0081652 - .0024637 * (27.94 - TD)**.35) * (D**(1.1 + .001085
     1 * (27.94 - TD)**2.0)) * HT + .0007838
      RETURN
C
C     *****
C     * JUNIPER
C     *****
C
   10 IF(STEMS.LE.1.0) STEMS = 1.000000
      V = (((20.0 - STEMS) / 19.0)**(2.25 +.15012 * (TD - 2.54)) * (1.0
     181 + .0246575 * (TD - 2.54)) * ((8.52E-05 * D**1.8) + (1.3194E-11
     2 * D**5.0))) * HT + .0008682
      RETURN
   20 V = 0.0
      RETURN
      END
```

Table 1.--*Pinyon gross cubic-foot volume outside bark including stump and limbs to 1-inch minimum top diameter limit*

Basal diameter (inches)	Total height (feet)									
	5	10	15	20	25	30	35	40	45	50
1	0	0	0	0	0	0	0	0	0	0
2	[1]0.056	0.084	0.112	0.140	0.168	0.196	0.224	0.252	0.280	0.309
4	.231	.433	.636	.839	1.042	1.245	1.448	1.651	1.854	2.057
6	.537	1.045	1.554	2.063	2.572	3.081	3.590	4.099	4.608	5.117
8	.960	1.893	2.825	3.758	4.690	5.623	6.555	7.488	8.420	9.353
10	1.494	2.960	4.425	5.891	7.357	8.823	10.289	11.755	13.221	14.687
12	2.131	4.235	6.339	8.442	10.546	12.650	14.753	16.857	18.961	21.065
14	2.869	5.711	8.553	11.394	14.236	17.078	19.919	22.761	25.603	28.444
16	3.704	7.381	11.057	14.734	18.410	22.087	25.763	29.440	33.116	36.793
18	4.633	9.239	13.844	18.450	23.055	27.661	32.267	36.872	41.478	46.083
20	5.654	11.280	16.907	22.533	28.160	33.786	39.412	45.039	50.665	56.292
22	6.765	13.502	20.239	26.976	33.713	40.450	47.187	53.924	60.661	67.398
24	7.963	15.899	23.835	31.770	39.706	47.642	55.577	63.513	71.449	79.385
26	9.248	18.469	27.690	36.911	46.131	55.352	64.573	73.794	83.014	92.235
28	10.618	21.209	31.800	42.391	52.982	63.573	74.163	84.754	95.345	105.936
30	12.072	24.117	36.161	48.206	60.250	72.295	84.340	96.384	108.429	120.473
32	13.608	27.189	40.770	54.351	67.932	81.512	95.093	108.674	122.255	135.836
34	15.226	30.425	45.623	60.821	76.020	91.218	106.417	121.615	136.814	152.012
36	16.924	33.821	50.717	67.614	84.510	101.407	118.303	135.200	152.096	168.993
38	18.702	37.376	56.050	74.724	93.398	112.072	130.746	149.420	168.094	186.768
40	20.558	41.088	61.618	82.148	102.678	123.208	143.738	164.268	184.798	205.328

[1]Blocked in area represents extent of data.

Table 2.--*Pinyon gross cubic-meter volume outside bark including stump and limbs to 2.5-centimeter minimum top diameter limit*

Basal diameter (centimeters)	Total height (meters)								
	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5
2.5	0	0	0	0	0	0	0	0	0
5.0	0.0015	0.0023	0.0030	0.0038	0.0046	0.0053	0.0061	0.0068	0.0076
10.0	.0062	.0117	.0172	.0226	.0281	.0336	.0390	.0445	.0500
15.0	.0145	.0282	.0420	.0557	.0694	.0831	.0968	.1106	.1243
20.0	.0259	.0511	.0763	.1014	.1266	.1518	.1769	.2021	.2273
25.0	.0404	.0799	.1195	.1591	.1987	.2383	.2779	.3174	.3570
30.0	.0576	.1144	.1713	.2281	.2849	.3417	.3986	.4554	.5122
35.0	.0776	.1544	.2312	.3079	.3847	.4615	.5383	.6151	.6919
40.0	.1002	.1996	.2989	.3983	.4977	.5971	.6965	.7958	.8952
45.0	.1253	.2498	.3744	.4989	.6234	.7480	.8725	.9970	1.1216
50.0	.1530	.3051	.4573	.6095	.7616	.9138	1.0660	1.2182	1.3703
55.0	.1830	.3653	.5475	.7298	.9120	1.0943	1.2765	1.4588	1.6410
60.0	.2155	.4302	.6449	.8597	1.0744	1.2891	1.5038	1.7185	1.9332
65.0	.2503	.4999	.7494	.9989	1.2485	1.4980	1.7475	1.9971	2.2466
70.0	.2874	.5741	.8608	1.1474	1.4341	1.7207	2.0074	2.2941	2.5807
75.0	.3268	.6529	.9790	1.3050	1.6311	1.9571	2.2832	2.6093	2.9353
80.0	.3685	.7362	1.1039	1.4716	1.8393	2.2070	2.5747	2.9424	3.3101
85.0	.4123	.8239	1.2355	1.6470	2.0586	2.4701	2.8817	3.2932	3.7046
90.0	.4584	.9160	1.3736	1.8312	2.2888	2.7464	3.2040	3.6616	4.1192
95.0	.5066	1.0124	1.5182	2.0240	2.5298	3.0356	3.5414	4.0472	4.5530
100.0	.5569	1.1131	1.6692	2.2253	2.7815	3.3376	3.8937	4.4499	5.0060

Table 3.--*Pinyon gross cubic-foot volume proportion of 1-inch minimum top diameter limit*

Basal diameter (inches)	Minimum top diameter limit (inches)						
	1	2	3	4	5	6	7
2	1.000	0	0	0	0	0	0
4	1.000	0.677	0.300	0	0	0	0
6	1.000	.852	.637	0.411	0.192	0	0
8	1.000	.914	.765	.607	.454	0.305	0.154
10	1.000	.939	.819	.692	.574	.467	.365
12	1.000	.949	.842	.730	.630	.545	.472
14	1.000	.952	.850	.745	.655	.582	.525
16	1.000	.952	.851	.750	.664	.598	.550
18	1.000	.949	.847	.747	.665	.602	.560
20	1.000	.945	.842	.742	.660	.600	.561
22	1.000	.941	.835	.734	.653	.594	.557
24	1.000	.936	.828	.726	.644	.586	.551
26	1.000	.932	.820	.717	.635	.577	.542
28	1.000	.927	.813	.707	.625	.567	.533
30	1.000	.922	.805	.698	.615	.557	.523
32	1.000	.918	.797	.689	.605	.547	.513
34	1.000	.913	.790	.680	.596	.538	.504
36	1.000	.909	.783	.672	.587	.528	.494
38	1.000	.904	.776	.663	.577	.519	.485
40	1.000	.900	.769	.655	.569	.510	.476

Table 4.--*Pinyon gross cubic-meter volume proportion of 2.5 centimeter minimum top diameter limit*

Basal diameter (centimeters)	Minimum top diameter limit (centimeters)			
	2.5	5.0	10.0	15.0
2.5	1.00000	0	0	0
5.0	1.00000	0	0	0
10.0	1.00000	0.67600	0	0
15.0	1.00000	.85278	0.41110	0
20.0	1.00000	.91509	.60845	0.30488
25.0	1.00000	.94118	.69524	.46835
30.0	1.00000	.95158	.73448	.54803
35.0	1.00000	.95505	.75083	.58607
40.0	1.00000	.95465	.75559	.60266
45.0	1.00000	.95230	.75392	.60744
50.0	1.00000	.94892	.74867	.60563
55.0	1.00000	.94479	.74144	.60006
60.0	1.00000	.94036	.73314	.59228
65.0	1.00000	.93577	.72425	.58333
70.0	1.00000	.93118	.71519	.57372
75.0	1.00000	.92655	.70609	.56389
80.0	1.00000	.92203	.69711	.55406
85.0	1.00000	.91757	.68830	.54432
90.0	1.00000	.91324	.67974	.53481
95.0	1.00000	.90901	.67143	.52557
100.0	1.00000	.90489	.66340	.51662

Table 5.--*Juniper gross cubic-foot volume outside bark including stump and limbs to 1-inch minimum top diameter limit for single stemmed trees*

Basal diameter (inches)	Total height (feet)									
	5	10	15	20	25	30	35	40	45	50
1	0	0	0	0	0	0	0	0	0	0
2	0.057	0.084	0.110	0.137	0.163	0.190	0.216	0.243	0.270	0.296
4	.222	.414	.606	.798	.989	1.181	1.373	1.565	1.756	1.948
6	.512	.993	1.474	1.955	2.436	2.917	3.398	3.880	4.361	4.842
8	.913	1.796	2.678	3.561	4.443	5.326	6.208	7.091	7.973	8.856
10	1.421	2.811	4.201	5.591	6.981	8.371	9.761	11.151	12.541	13.931
12	2.032	4.033	6.033	8.034	10.035	12.036	14.037	16.038	18.039	20.040
14	2.746	5.461	8.177	10.892	13.607	16.323	19.038	21.753	24.469	27.184
16	3.566	7.102	10.638	14.174	17.709	21.245	24.781	28.316	31.852	35.388
18	4.498	8.965	13.432	17.899	22.367	26.834	31.301	35.768	40.235	44.703
20	5.548	11.066	16.583	22.101	27.618	33.136	38.653	44.171	49.689	55.206
22	6.728	13.426	20.123	26.821	33.518	40.216	46.913	53.611	60.308	67.006
24	8.051	16.073	24.094	32.115	40.136	48.157	56.178	64.199	72.220	80.241
26	9.536	19.042	28.547	38.053	47.558	57.064	66.570	76.075	85.581	95.086
28	11.203	22.375	33.547	44.719	55.891	67.063	78.236	89.408	100.580	111.752
30	13.077	26.122	39.168	52.214	65.260	78.306	91.352	104.398	117.444	130.490
32	15.187	30.343	45.500	60.656	75.813	90.969	106.125	121.282	136.438	151.595
34	17.569	35.106	52.643	70.181	87.719	105.256	122.794	140.331	157.869	175.407
36	20.259	40.488	60.716	80.945	101.173	121.402	141.630	161.859	182.087	202.316
38	23.304	46.577	69.851	93.124	116.397	139.671	162.944	186.217	209.491	232.764
40	26.712	53.474	80.136	106.918	133.639	160.361	187.083	213.804	240.526	267.248

Table 6.--*Juniper gross cubic-meter volume outside bark including stump and limbs to 2.5-centimeter top diameter limit for single stemmed trees*

Basal diameter (centimeters)	Total height (meters)								
	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5
2.5	0	0	0	0	0	0	0	0	0
5.0	0.0016	0.0023	0.0030	0.0037	0.0045	0.0052	0.0059	0.0066	0.0073
10.0	.0061	.0112	.0164	.0216	.0268	.0320	.0372	.0424	.0476
15.0	.0139	.0269	.0399	.0529	.0660	.0790	.0920	.1050	.1180
20.0	.0247	.0486	.0725	.0964	.1203	.1442	.1680	.1919	.2158
25.0	.0385	.0761	.1137	.1513	.1889	.2265	.2641	.3018	.3394
30.0	.0550	.1091	.1633	.2174	.2715	.3257	.3798	.4339	.4881
35.0	.0743	.1478	.2212	.2946	.3681	.4415	.5150	.5884	.6619
40.0	.0965	.1921	.2877	.3833	.4789	.5745	.6701	.7657	.8613
45.0	.1216	.2423	.3631	.4838	.6046	.7253	.8461	.9668	1.0875
50.0	.1499	.2990	.4480	.5971	.7461	.8952	1.0442	1.1933	1.3423
55.0	.1817	.3625	.5433	.7241	.9049	1.0857	1.2665	1.4473	1.6282
60.0	.2172	.4336	.6500	.8664	1.0827	1.2991	1.5155	1.7318	1.9482
65.0	.2571	.5132	.7694	1.0256	1.2818	1.5380	1.7942	2.0503	2.3065
70.0	.3017	.6024	.9032	1.2040	1.5048	1.8056	2.1064	2.4072	2.7080
75.0	.3517	.7025	1.0533	1.4042	1.7550	2.1058	2.4567	2.8075	3.1583
80.0	.4079	.8150	1.2220	1.6291	2.0362	2.4432	2.8503	3.2573	3.6644
85.0	.4712	.9416	1.4119	1.8823	2.3526	2.8230	3.2934	3.7637	4.2341
90.0	.5426	1.0843	1.6260	2.1678	2.7095	3.2512	3.7929	4.3346	4.8764
95.0	.6232	1.2455	1.8677	2.4900	3.1123	3.7346	4.3569	4.9792	5.6015
100.0	.7142	1.4276	2.1409	2.8542	3.5676	4.2809	4.9943	5.7076	6.4209

Table 7.--*Juniper gross cubic-foot volume proportion of 1-inch minimum top diameter limit for single stemmed trees*

Basal diameter (inches)	Minimum top diameter limit (inches)						
	1	2	3	4	5	6	7
2	1.000	0	0	0	0	0	0
4	1.000	0.517	0.168	0	0	0	0
6	1.000	.710	.448	0.230	0.074	0	0
8	1.000	.802	.610	.430	.270	0.138	0.044
10	1.000	.855	.709	.565	.428	.300	.188
12	1.000	.890	.775	.659	.544	.432	.325
14	1.000	.914	.822	.728	.631	.534	.439
16	1.000	.931	.857	.779	.697	.614	.530
18	1.000	.944	.883	.818	.749	.677	.604
20	1.000	.954	.904	.848	.789	.728	.663
22	1.000	.962	.919	.872	.822	.768	.712
24	1.000	.968	.932	.891	.847	.800	.751
26	1.000	.973	.942	.906	.868	.826	.782
28	1.000	.977	.949	.919	.884	.847	.808
30	1.000	.980	.956	.928	.898	.864	.829
32	1.000	.982	.961	.936	.908	.878	.845
34	1.000	.984	.964	.942	.916	.888	.859
36	1.000	.985	.967	.946	.923	.897	.869
38	1.000	.987	.970	.950	.928	.904	.878
40	1.000	.988	.972	.953	.932	.909	.884

Table 8.--*Juniper gross cubic-meter volume proportion of 2.5 centimeter minimum top diameter limit for single stemmed trees*

Basal diameter (centimeters)	Minimum top diameter limit (centimeters)			
	2.5	5.0	10.0	15.0
2.5	1.00000	0	0	0
5.0	1.00000	0	0	0
10.0	1.00000	0.51891	0	0
15.0	1.00000	.70932	0.23051	0
20.0	1.00000	.80120	.42956	0.13809
25.0	1.00000	.85445	.56423	.29935
30.0	1.00000	.88916	.65827	.43044
35.0	1.00000	.91313	.72624	.53256
40.0	1.00000	.93069	.77743	.61245
45.0	1.00000	.94372	.81655	.67559
50.0	1.00000	.95381	.84713	.72599
55.0	1.00000	.96161	.87121	.76637
60.0	1.00000	.96777	.89041	.79899
65.0	1.00000	.97264	.90566	.82532
70.0	1.00000	.97644	.91787	.84657
75.0	1.00000	.97951	.92762	.86366
80.0	1.00000	.98193	.93538	.87742
85.0	1.00000	.98382	.94155	.88841
90.0	1.00000	.98534	.94648	.89720
95.0	1.00000	.98656	.95041	.90424
100.0	1.00000	.98756	.95359	.90992

Table 9.--*Juniper gross cubic-foot volume proportion of single stemmed trees for multiple stemmed trees*

Number of stems	Minimum top diameter limit (inches)						
	1	2	3	4	5	6	7
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	.885	.867	.850	.832	.815	.799	.782
3	.779	.746	.715	.686	.657	.630	.604
4	.679	.636	.596	.558	.523	.490	.458
5	.588	.537	.491	.448	.410	.374	.342
6	.503	.448	.399	.355	.316	.281	.250
7	.426	.368	.319	.276	.239	.207	.179
8	.356	.298	.250	.210	.176	.148	.124
9	.292	.237	.193	.156	.127	.103	.084
10	.236	.193	.145	.113	.089	.069	.054
11	.186	.140	.105	.079	.060	.045	.034
12	.143	.103	.074	.053	.038	.027	.020
13	.106	.072	.049	.034	.023	.016	.011
14	.075	.048	.031	.020	.013	.008	.005
15	.050	.030	.018	.011	.006	.004	.002
16	.030	.017	.009	.005	.003	.002	.001
17	.016	.008	.004	.002	.001	.000	.000
18	.006	.003	.001	.000	.000	.000	.000
19	.001	.000	.000	.000	.000	.000	.000
20	.000	.000	.000	.000	.000	.000	.000

Table 10.--*Juniper gross cubic meter volume proportion of single stemmed trees for multiple stemmed trees*

Number of stems	Minimum top diameter limit (centimeters)			
	2.5	5.0	10.0	15.0
1	1.00000	1.00000	1.00000	1.00000
2	.88576	.86797	.83346	.80033
3	.77916	.74730	.68745	.63242
4	.68008	.63760	.56045	.49265
5	.58839	.53845	.45093	.37765
6	.50403	.44946	.35741	.28424
7	.42682	.37018	.27846	.20948
8	.35667	.30019	.21266	.15067
9	.29343	.23904	.15865	.10532
10	.23696	.18626	.11511	.07116
11	.18709	.14138	.08075	.04615
12	.14367	.10388	.05434	.02846
13	.10651	.07326	.03470	.01648
14	.07540	.04897	.02070	.00880
15	.05013	.03043	.01126	.00423
16	.03044	.01702	.00538	.00178
17	.01602	.00808	.00213	.00065
18	.00653	.00288	.00065	.00024
19	.00149	.00058	.00019	.00015
20	.00014	.00014	.00014	.00015

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Presents cubic-volume equations and tables for estimating gross cubic volume outside bark of individual pinyon and juniper trees in northern New Mexico; also shows procedures used in building mathematical model.

KEYWORDS: gross cubic-volume, equations, pinyon, juniper, mathematical models.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

Billings, Montana
Boise, Idaho
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Logan, Utah (in cooperation with Utah State University)
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